World Conference on Timber Engineering
Oslo 2023

IMPACT SOUND INSULATION PERFORMANCE OF RAISED DISCRETE FLOATING FLOOR ASSEMBLIES ON MASS TIMBER SLABS

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ABSTRACT: Bare mass timber structural slabs have relatively low impact sound insulation performance. Though certain floating floor assemblies on mass timber slabs can provide adequate single number ratings, such assemblies are mainly effective in the middle to high frequency range. This study presents the impact sound insulation performance of raised discrete floating floor assemblies for mass timber slabs. The raised discrete floating floor assemblies were composed of elastomer blocks, insulation materials**,** wood-based sheathing panels and concrete topping or cement boards. Impact sound insulation tests were conducted on a mock-up building under different excitation sources including human walking, ISO tapping machine and ISO rubber ball. The results showed that raised discrete floating floor assemblies tested in this study could improve the impact sound insulation ratings of the bare slabs by up to 41 dBA under ISO tapping machine excitation. Under different excitation sources, the impact sound pressure level spectra obtained from ISO rubber ball had similar frequency characteristics with that from human walking, though the magnitudes were higher at each octave band. The discrete raised floor without any mass topping had similar performance (L_{Fmax}=74.3 dBA) in attenuating low frequency sound to the continuous floating concrete topping of 50 mm thickness. The advantage of the raised discrete floor assemblies with dry solution boards over the continuous floating concrete topping assemblies based on the ISO tapping machine tests did not exist with the ISO rubber ball testing. Higher topping mass resulted in lower L_{Fmax}.

KEYWORDS: Impact sound insulation, Floating floor, Mass timber, Dry construction

1 INTRODUCTION

Mass timber panels including cross laminated timber (CLT), dowel laminated timber (DLT), nail laminated timber (NLT) and other large-dimension engineered wood panels are used largely as floor slabs in mass timber buildings and hybrid timber buildings due to their dry and fast construction. Exposed wood ceiling is appealing to both designers and occupants. However, bare mass timber panels have relatively low impact sound insulation performance [1], especially in the low-frequency range [2]. The common solution is to add a floating mass topping, such as a concrete topping, to improve the impact sound insulation performance [3]. However, continuous floating concrete topping assemblies had limited improvements on mass timber slabs [4]. It was reported that the apparent impact insulation class (AIIC) of CLT slabs with only continuous concrete topping floated on various market available elastic interlayers was difficult to achieve more than 55 dBA [4].

Conventional raised floor system is normally designed to provide an even finishing floor surface and space for ducts and cables, which is not meant for attenuating impact sound or insulating airborne sound. The discrete raised floor system incorporates elastic mounts for vibration isolation between the raised floor assembly and the structural floor for improved sound insulation performance. Homb et. al. reported that the such floor assemblies had high performance in middle to high frequency range on the light wood frame structural floor [6]. Its acoustic performance has not been fully explored compared with the continuous floating floor system, especially on mass timber floors. Previous study showed that raised discrete floating concrete floor had the potential to provide high impact sound insulation performance for CLT slabs according to typical ISO tapping machine testing [7]. However, it is not clear whether the system performs the same under different excitation sources, especially in the low frequency range, which is of great importance to the application in mass timber buildings.

This study aims to further investigate the impact sound insulation performance of raised discrete floating floors on mass timber slab, especially under different excitation sources including ISO tapping machine, ISO rubber ball and human walking. Moreover, the proposed assemblies

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https://doi.org/10.52202/069179-0260

adopt dry construction concepts to minimize cast-in-place concrete toppings.

2 MATERIALS AND METHODS

2.1 MATERIALS

Both CLT and DLT, were selected as the structural floors for testing. The CLT floor was made of 3 pieces of 5-layer (139-mm-thick, 35/17/35/17/35) spruce-pine-fir (SPF) CLT panels (CrossLam CLT 139V). Each CLT panel was 4.0 m long and 1.8 m wide. The DLT floor was made of 2 pieces of 140-mm-thick SPF DLT panels (StructureCraft) with 11 mm oriented strand board (OSB) on the top. Each DLT panel was 5.4 m long and 2.0 m wide. The panel-to-panel and panel-to-wall were connected with ϕ8.5**×**215 mm fully-thread self tapping screws with spacing of 40 cm. All gaps were sealed by acoustic sealant and tapes.

The raised discrete floating floor assemblies illustrated in Figure 1 were composed of elastomer blocks (AFB (Getzner), AMC25 and AMC40 (AMC Mecanocaucho)), Rockwool insulation material, OSB sheathing panels and mass topping. The AFB had a capacity of 60 kg load per mount, while AMC25 and AMC40 had designed capacity of 25 kg and 40 kg per mount respectively. AFB blocks were glued onto the structural floor with 60 cm spacing. Wood sleepers with a dimension of 19mm × 64mm were glued on the top of AFB blocks by polyurethane glue. 11-mm- thick OSB panels were fastened together with wood sleeper by 38 mm-long wood screws, and the remaining cavity was filled with 89 mm Rockwool insulation. AMC floor block series was made by 50 mm × 50 mm × 25 mm elastomer blocks and AMC innovated metal mounting frame. AMC floor mounts were fixed on structural floor by two 38 mm long wood screws with 50 cm spacing between each mount point. Then, the 50 mm by 50 mm wood sleepers were placed and fixed on the mounts, and 89 mm Rockwool insulation filled the cavity. Finally, 11 mm OSB panel was placed on the top of wood sleepers and fastened by 38 mm in length wood screws.

Four pre-cast 1.6 m × 1.6m normal strength (35 MPa) concrete toppings (38 mm, 50 mm, 70 mm and 100 mm) were floated as mass toppings. The concrete masses were 234, 307, 430 and 614 kg, equivalent to an area density of 91, 120, 168 and 240 kg/m^2, respectively. Besides the pre-cast concrete toppings, two types of cement boards and one type of gypsum board were selected as the dry-solution for floating floor. Fire rated gypsum board is the most commonly used drywall material in residential construction, and it demonstrates fire-resistance property to enhance the fire resistance level of the discrete floating floor. Each floated layer of 11 mm cement board (HardieBacker 500), 11 mm USG cement board and 11 mm gypsum board contributed to 13.4, 11.9 and 7.8 kg/m^2 area density to the system, and two layers of cement boards met the basic requirement of fire resistance [8]**Error! Reference source not found.**. All the cement board and gypsum board toppings were connected with the raised discrete floating floor by 38 mm wood screws.

In the small scale tests, the discrete mount assemblies were about to have a dimension of 1.6 × 1.6 m. Both AMC25 and AMC40 block mounts were assembled as a 5.0 × 3.6 m floor after the impact sound tests on small scale assemblies. In the impact sound test of full size assemblies, double layer USG cement boards and 12.7 mm gypsum boards (7.8 kg/m^2) were installed as mass toppings. Because the raised discrete floating floor has multiple components, each assembly is named as Mass timber_Block type_Insulation_Topping. CLT_AFB_INS_C100 represents that the AFB discrete raised floor with Rockwool insulation in cavity floating 100 mm concrete topping was installed on the CLT structural floor. Moreover, CB and USG represent two types of cement boards while GYP is short for gypsum board. The number after each floating board name indicates the layer of board applied on the discrete raised floor. The full size assembly has "Full" as suffix after the component name.

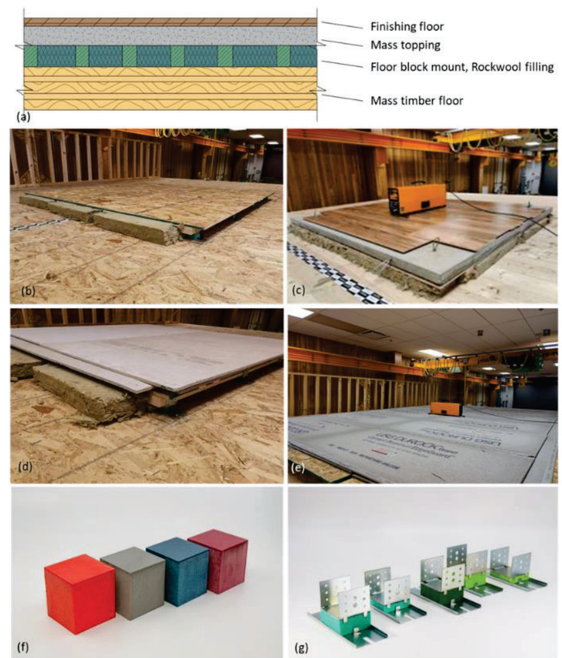

Figure 1: *(a) schematic diagram for discrete floating floor system, (b) raised discrete floor without mass topping, (c) floating concrete topping, (d) floating triple layer HardieBacker cement boards, (e) full-size floating double layer USG cement boards, (f) AFB floor mounts, and (g) AMC25 and AMC40 floor mounts*

2.2 IMPACT SOUND INSULATION TESTS

The impact sound insulation tests were conducted using a mock-up building as shown in Figure 2. The mock-up room was built with staggered wood stud walls (140 mm thick) with OSB sheathing panels, two layers of gypsum panels with resilience channels and rockwool insulation batts in the cavity. The mock-up has a height of 2.4 m, an outer floor size of 5.4×4 m^2 and an internal volume of 44 m^3. CLT and DLT floors were constructed on the mock-

https://doi.org/10.52202/069179-0260

up room. The apparent impact insulation class (AIIC) was be measured according to ASTM E1007-16 [9] using an ISO tapping machine (Larson Davis BAS004) and sound pressure meter (Larson Davis 831).

The impact tests using ISO rubber ball were conducted according to JIS A 1418 [10]. On the small scale 1.6 × 1.6 m floor assemblies, the rubber ball was dropped at 1.0 m from the floor surface for 4 consecutive times at center of floating floor with fixed location of sound level meter at the geometry center of receiving room. The locations of rubber ball dropping on full size floor assembly was according to Figure 2 (c). The rubber ball was dropped at each location for 4 times, and total of 20 impacts were recorded at the geometry center of receiving room. For real human walking excitation, a 75kg adult was walking on the floor in a random path for 1 minute, and the sound pressure level meter was fixed at receiving room center as well. L_{Fmax} single number rating was used to quantify the performance of floating floor assembly. The SPL of ISO rubber ball dropping was corrected according to [10].

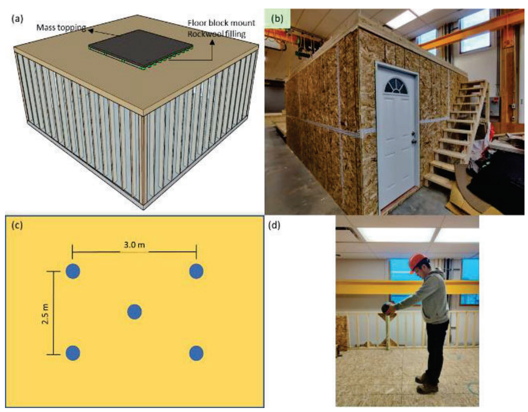

Figure 2: *(a) Sketch of the mock-up room, (b), photo of mock-up room (c) location of dropping rubber ball on full size floating floor and (d) dropping rubber ball*

3 RESULTS & DISCUSSION

3.1 APPARENT IMPACT SOUND INSULATION PERFORMANCE OF SELECTED ASSEMBLIES UNDER ISO TAPPING MACHINE EXCITATION

As listed in Table 1, the AIIC single number ratings for AFB discrete raised floor as well as 3 selected continuous floating floor assemblies on mass timber floor tested in [5]. With only AFB raised discrete floor on the bare CLT floor, AIIC rating increases from 26 to 47 dBA. This basic assembly without a mass topping has higher AIIC rating than that of most of floating concrete assemblies tested on the same CLT floor [4]. The insertion of Rockwool insulation (INS) in the cavity brought AIIC another 3 dBA higher to 50 dBA. The addition of 38 mm concrete topping further improved the AIIC to 58 dBA, which was higher than 55 dBA recommended by [11]. The increasing of concrete topping thickness does not affect much on AIIC rating of discrete floor system. The four concrete mass toppings each brought up single number rating 1 or 2 dBA gradually until 62 dBA with 100 mm concrete topping. The 50 mm mass topping with engineered floor finishing was tested as a potential solution for actual construction with an AIIC of 59 dBA. The overall impact sound insulation performance of AFB discrete raised floor assemblies on CLT and DLT structural floor are similar, which means that the type of structural floor does not affect the impact sound insulation performance of the discrete raised floor system. Furthermore, the concrete thickness did not affect the performance significantly, which indicated that dry construction boards such as cement boards and gypsum boards might be used.

Table 1: *Comparison AIIC ratings between AFB discrete floating assemblies and continuous floating concrete floors*

Structural Floor	AIIC ratings of different floating assemblies (dBA)								
	Bare Floor	AFB	AFB_INS	AFB_INS_C38	AFB_INS_C50	AFB_INS_C70	AFB_INS_C100	AFB_INS_C50 EngFloor	AFB_INS_SF_C50
CLT	21	47	50	58	59	60	62	62	62
DLT	37	43	53	N/A	58	N/A	61	61	60

The apparent normalized impact sound pressure level (ANISPL) curves of the discrete floating floor system on CLT is summarized in Figure 3 (a). As it can be seen, the discrete floating floor assemblies contributed significantly in both frequency regions below 315 Hz and higher than 1000 Hz. Using only AFB mounts covered by OSB, middle to high frequency impact sound pressure level decreased for at least 25 dBA on CLT. The Rockwool filling insulated middle frequency sound more effectively than extreme low or high regions on CLT. Adding a 50 mm concrete topping reduced sound pressure level in the low-to-mid frequency (100 – 400 Hz) up to 20 dBA. As a result, mass topping did not reduce sound pressure level in the high frequency (more than 400 Hz) as significant as it in low frequency range (lower than 400 Hz). A wide peak occurred between 400 and 630 Hz after adding the concrete topping, and that peak was not eliminated with further surface finishing. Still, installing the engineered floor can reduce the negative effect of hard concrete surface in the frequency range higher than 400 Hz. The sound pressure spectra for the assemblies on DLT are shown in Figure 3 (b). The bare DLT floor has much lower peak SPL than bare CLT. The curve for AFB mounts covered by OSB has a major peak at 160 Hz which does not appear in the assembly on CLT. Unlike the plateau below 400 Hz in Figure 3 (a), the spectra in Figure 3 (b) drops linearly right after the occurrence of 160 Hz peak. The filling of Rockwool in the cavity had almost even contribution throughout the entire frequency domain. These differences observed on DLT revealed that the structural floor had noticeable effect on impact sound insulation according to frequency, despite the AIIC single number ratings did not show strong differences in between. The spectra of floating the 50 mm concrete topping on DLT assembly demonstrates the similar characteristic as that on CLT, with generally flatter shape. The ANISPL spectra characteristics for further layers of toppings beyond the 50 mm concrete are more identical on DLT than CLT. The type of structural floor did not noticeably affect ANISPL spectra of discrete mounts floating concrete topping. In summary, the AFB discrete raised floating floors had high efficiency on impact sound insulation and demonstrated similar performance on both CLT and DLT under ISO tapping machine excitation.

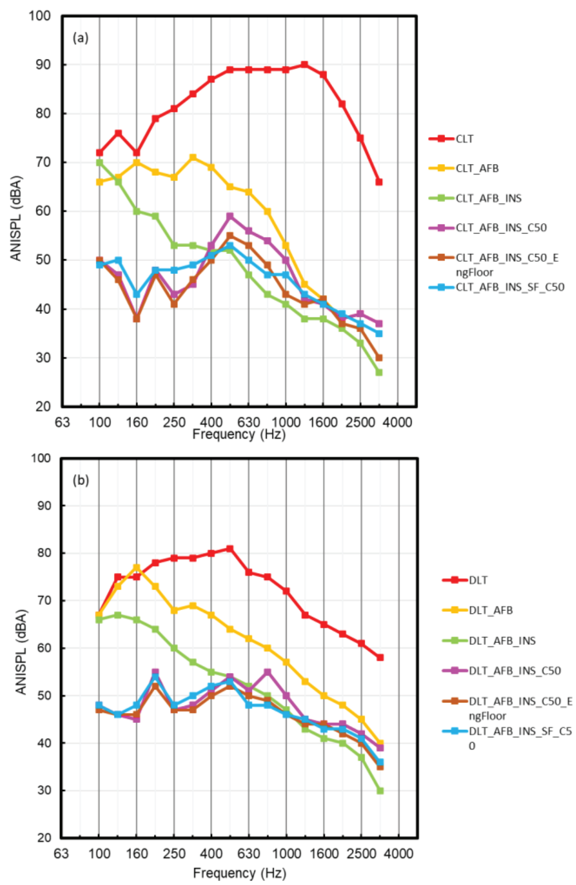

Figure 3: *Impact sound insulation performance of discrete floating floor on (a) CLT and (b) DLT structural floor under ISO tapping machine*

As the discrete raised floor floating concrete toppings have AIIC ratings more than 60 dBA, more types of discrete raised floor with various light-weight dry solutions were tested for pursuing a more environment friendly and lower mass assembly. The results of impact sound test on two types of AMC innovated mounts with various low-mass toppings are discussed below. The maximum allowable load for AMC25 is approximately equal to 38 mm concrete topping, and AMC40 has maximum load capacity for 50 mm normal strength concrete. This is the main reason of only conducting the impact sound test on one concrete topping on each discrete raised floor. The bare DLT floor has AIIC rating of 36 dBA, and the AMC25 floor mounts with OSB surface brought the single number rating 11 dBA higher, which was slightly lower than AFB. With Rockwool insulation, the single number rating increases to 55 dBA. According to Table 2, double layers of cement board (CB2) floating on AMC25 reaches the AIIC rating more than 60 dBA. However, the third layer of cement board (CB3) did not contribute much on impact sound insulation performance, which also indicated that the increase of mass did not contribute much to the performance. Floating double layer of cement boards would fulfil the fire resistance requirement and provided high performance impact sound insulation solution. The finishing layer of engineered wood floor on AMC25 floating CB2 assembly brought the AIIC 1 dBA higher. While this assembly had about only 30% mass of 38 mm concrete topping, the AIIC rating was 62 dBA, which was same as floating a 38 mm concrete topping.

Table 2: *AIIC rating of AMC25 and AMC40 floor block assemblies on DLT*

Floor Block Mount	AIIC ratings of different assemblies (dBA)							
	Bare DLT Floor	DLT_AMC	DLT_AMC_INS	DLT_AMC_INS_CB1	DLT_AMC_INS_CB2	DLT_AMC_INS_CB3	DLT_AMC_INS_CB2_Engfloor	DLT_AMC_INS_C38	DLT_AMC_INS_C50
AMC25	36	47	55	58	61	61	62	62	N/A
AMC40	36	47	52	57	60	60	62	N/A	57

AMC40 has higher allowable load of 40 kg/mount and is able to float 50 mm concrete topping. Floating of 50 mm concrete topping had the same AIIC rating as floating single layer of cement board, with the same single number rating of 57 dBA. Meanwhile, floating CB2 reached the AIIC rating 60 dBA. Similar as AMC25 discrete raised floor, the third layer of CB did not contribute to improving impact sound insulation performance. Comparing the impact sound insulation performance between the AMC25 and AMC40 discrete raised floor floating multiple layers of cement boards, the difference between single number ratings was below 3 dBA benchmark. The increment from single to double layer had slight increase on AIIC, and it kept the same with floating the third layer. Floating 3 layers of CB did not have any noticeable contribution on impact sound insulation. The advantage of higher mass for concrete topping was not favoured in the AMC25 and AMC40 discrete floating floor assemblies, however, the dry solution with cement boards demonstrated high impact sound insulation performance on the discrete raised floor. Choosing adequate floor mount corresponding to topping load is important in

https://doi.org/10.52202/069179-0260

practical applications though the difference was within 3 dBA benchmark.

3.2 IMPACT SOUND PRESSURE LEVEL SPECTRA UNDER DIFFERENT EXCITATION SOURCES

As the correction considering background noise and reverberation time is different in ASTM E1007-16 [9] and JIS A 1418 [10] is different, the directly measured SPL spectra are plotted in Figure 4 for comparison. The two standard impact sources have higher SPL than real human's walking with the steel-toe safety boots on both bare CLT and DLT. It is obvious the ISO tapping machine generated higher SPL on both structural floors. SPL spectra for both rubber ball and human walking demonstrate similar trend on mass timber floors, except the curves for rubber ball are about 20 dBA higher than human walking throughout the entire frequency domain. The SPL of tapping machine increases above 80 Hz, however that decreases for the rubber ball which is more similar to human walking SPL spectra. Human walking generated impact sound between 40 and 50 dBA, with the peak value merely 55 dBA for both SPL curves. The difference between maximum and minimum SPL on human walking is about 15 dBA, which is similar to the trend of rubber ball spectra.

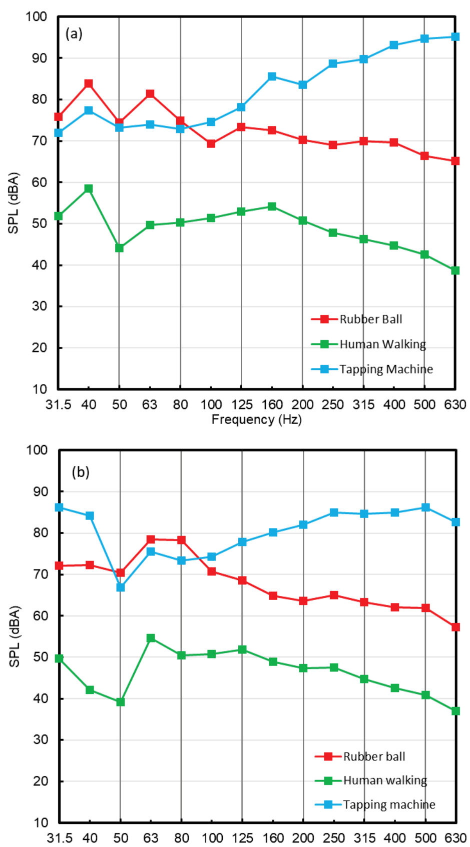

__Figure 4:__ Sound pressure level curves under different impact sources on bare (a) CLT and (b) DLT

The SPL curves with three different sound sources on selected (a) continuous and (b) discrete raised floating floors on the DLT floor are shown in Figure 5. The continuous floating concrete assembly consists an elastic interlayer (AFM 35, Getzner) and a 50 mm thick concrete topping. The rubber ball demonstrates the same SPL trend as human walking, and the overall SPL difference between them is within 15 dBA. However, the SPL difference between tapping machine and human walking curve increases up to 30 dBA at 630 Hz. However, the SPL curve characteristics of rubber ball and tapping machine are similar to each other, except the rubber ball generated higher impact sound below 100 Hz. In the frequency range below 125 Hz, all three curves have similar trends with peaks and drops occur at 63 and 50 Hz, respectively. The SPL drop linearly above 125 Hz about 15 dBA for all spectrum, while the total SPL is mainly below 40 dBA.

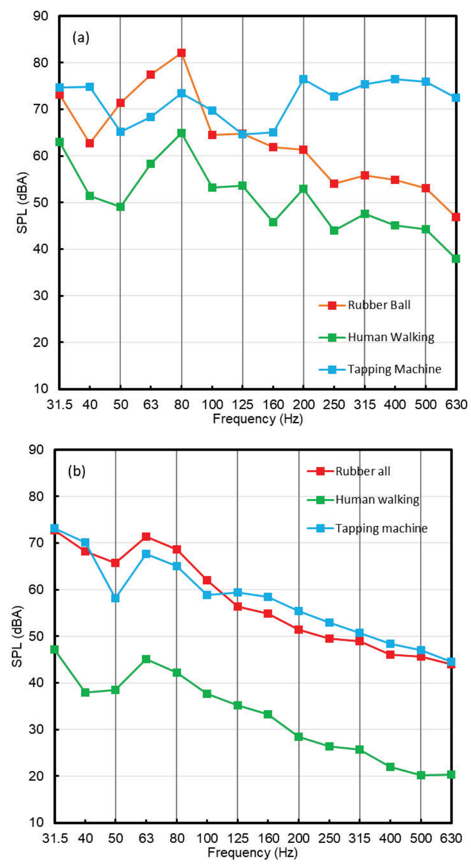

__Figure 5:__ Comparison of impact sound levels (50-630 Hz) of (a) continuous and (b) discrete floating floor assembly under different excitation sources

In summary, rubber ball is an excitation source which can generate SPL spectra of similar frequency characteristics with that by human walking on mass timber floors. This is in contradictory to the conclusion that CLT bare floors mimicked the impact sound pressure level values of a bare concrete floor in [12], which was tested using the tapping

https://doi.org/10.52202/069179-0260

machine. ISO rubber ball is more suitable for impact sound testing of mass timber floors in the current study.

3.3 IMPACT SOUND PERFORMANCE UNDER ISO RUBBER BALL EXCITATION

As discussed above, floating double layer cement boards on the base raised floor showed high performance using the tapping machine. Further investigations and modifications are based on this assembly. Two types of cement boards and one gypsum board were selected as the alternative mass topping to concrete topping. According to Table 3*:* , the AMC40 raised floor floating 50 mm concrete topping is still the best solution with L_{Fmax} of only 64.8 dBA. Among the result of floating dry solution boards above, full size assembly of floating the double layer of USG (USG2) has the best performance. The full size USG2 improved the single number rating for 3 dBA on AMC40 discrete raised floor. However, the single number rating after installing GYP2 was 2 dBA lower than the AMC40 basic assembly. However, at the current stage, there is no performance criteria based the L_{Fmax} single number rating developed for mass timber floors. Future research is required if ISO rubber ball is adopted for standardized testing and evaluation of impact sound insulation performance of mass timber floor assemblies.

Table 3: *L_{Fmax} single number rating for selected discrete floating floor assemblies*

Bare DLT	Bare CLT	DLT+AMC40+INS	DLT+AMC40+INS+ CB2	DLT+AMC40+INS+ CB2 Engfloor	DLT+AMC40+INS+ C50	DLT+AMC40+INS+ USG2 Full	DLT+AMC40+INS+ USG2 Full Engfloor	DLT+AMC40+INS+ GYP2 Full
78.4	81.3	74.3	75.3	71.4	64.8	71.3	71.0	76.5

The impact sound pressure level spectra of two full size assemblies and selected small size floors are summarized in Figure 3.1. Even though JIS 1418 only requires the frequency between 50 and 630 Hz to derive the L_{Fmax} single number rating, the SPL spectra in this figure includes 31.5 to 3150 Hz which beyond the frequency region of both JIS 1418 and ASTM E1007, which shows a wider perspective on rubber ball impact sound test on discrete raised floating floor assemblies. In Figure 3.1 (a), the discrete floating floor assemblies are efficient in higher frequency region. Considering 40 dBA as a benchmark for a quiet room, most assemblies insulate the noise above 1250 Hz very effectively. Floating a 50 mm concrete topping insulates the noise above 200 Hz and makes most noise inaudible, and the assembly with floating 50 mm concrete topping had average 6-10 dBA lower SPL than floating the other dry solution toppings, and the 50 mm concrete topping had about 10 times of unit mass of the cement boards, so adding extra mass further reduced the resonant frequency of the assembly and improved the impact sound insulation performance.

In SPL curves of floating dry solution boards, an obvious peak occurs between 50 and 80 Hz where the L_{Fmax} ratings come from shown in Table 3*:* . On discrete floating floor system, mass may not be the only factor which affects the impact sound insulation performance, and material selection is critical. The least dense gypsum board (GYP) had better performance than the densest CB between 63 and 200 Hz. Double layer of USG boards brought the SPL below 40 dBA at 630 Hz which was at much lower frequency than 1250 Hz for CB2 and GYP2. Applying 40 dBA cut-off line in the SPL spectra i, floating 50 mm concrete topping dropped below that at 250 Hz. Material property should be considered on selecting the dry solution mass toppings. In summary, the full size USG2 assembly on AMC40 has outstanding performance. The SPL difference between this assembly and floating a small scale 50 mm concrete is within 5 dBA in average.

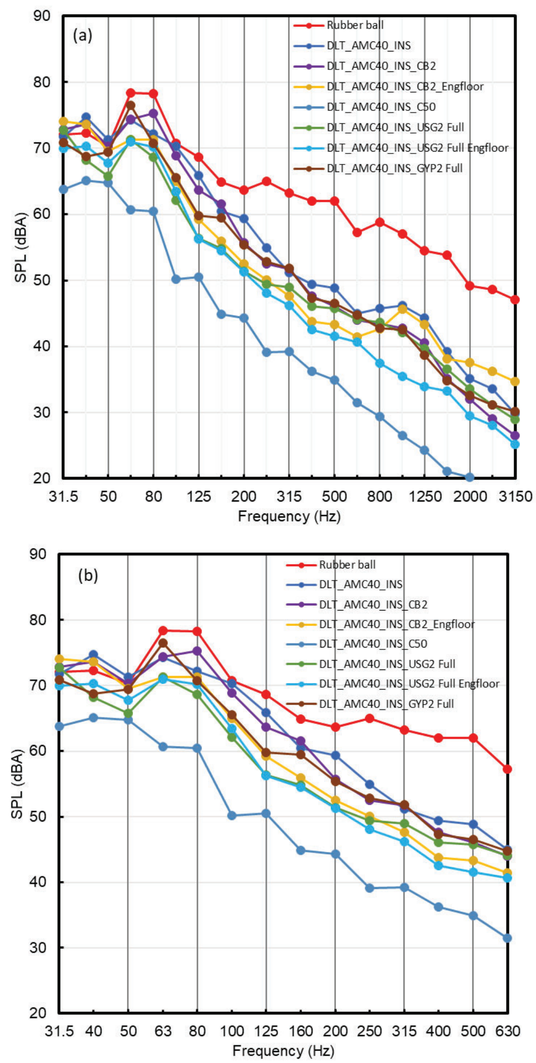

Figure 3.1 (a) The impact sound of discrete floating floor assemblies using the rubber ball (31.5 - 3150 Hz)

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4 CONCLUSIONS

The raised discrete floating floor assemblies tested in this study provide high impact sound insulation performance on mass timber slabs. However, the excitation sources are of great importance to the evaluation of the performance.

1. The raised discrete floating floor is an effective method to attenuate impact sound on mass timber floor tested with ISO tapping machine according to ASTM standards. The raised discrete floor system with all three types of floor block mounts were able to reach AIIC higher than 60 dBA. The type of structural floor (CLT and DLT) did not have strong effect on impact sound insulation performance, and the thickness of concrete topping was not critical on improving the AIIC ratings.
2. The comparison between AMC25 and AMC40 floor mounts concluded that the load capacity of floor block mount had minor influence on impact sound insulation performance, and the discrete raised floors had similar SPL curve characteristics. Floating dry solution boards had similar single number rating as floating 38-50mm thick concrete topping, and it can attenuate middle to high frequency sound more effectively.
3. The ISO rubber ball is able to generate impact sound SPL spectra of similar frequency characteristics with that by human walking on bare mass timber floors and both continuous and discrete raised floating floors considering. When tested with the rubber ball, the discrete raised floating floor assembly with dry solution boards has similar single number rating as the selected elastic interlayers floating 50 mm concrete topping. The discrete raised floating floor assembly with 50 mm thick concrete had the lowest L_{Fmax}. However, performance criteria is need for adopting the rubber ball for impact sound insulation performance testing and evaluation of mass timber floors.

ACKNOWLEDGEMENT

The financial support from BC Forest Innovation Invest - Wood First program, the Natural Sciences and Engineering Research Council of Canada (NSERC) and University of Northern British Columbia (UNBC) is greatly acknowledged. We acknowledge the in-kind contributions from StructureCraft, Structurlam, Getzner and AMC Mecanocaucho, as well as the technical supports from Wood Innovation Research Lab at UNBC.

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