Laboratory data examining impact and airborne sound attenuation in heavy timber loft style construction.

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ABSTRACT

An increasingly popular trend in urban neighborhoods is to convert old factory or industrial spaces into “loft” style condominiums. The structure in these old factory spaces tends to be comprised of heavy timber floor-ceiling systems. A floor-ceiling system, representative of what is found in the field, was constructed in the laboratory to complete impact insulation and airborne sound testing in accordance with ASTM E492 and ASTM E90 respectively. The baseline assembly was constructed of 300mm x 300mm (12”x12”) wood beams spaced 100 mm (48” OC), 57mm x 133 mm (nom 3”x6”) wood planks, and 19 mm x 149 mm (nom 1”x6”) wood planks laid perpendicular to the layer below. No ceiling was used, as part of the commercial desire for this type of space is the exposed wood ceiling. The baseline assembly tested to IIC 24 and STC 29.Various floor toppings were tested and the resulting IIC and STC data is presented in the paper.

1. INTRODUCTION

In the design process of multi family housing projects, aesthetic choices often create sound isolation challenges. Such is the case with “loft style” condominiums. For the purpose of this study “loft style” condominiums are considered those that are converted from old factory or industrial spaces. These units typically are constructed of large wood beams and plank wood floors. Potential buyers perceive the exposed wood beams and ceiling to be a highly desirable feature of the unit. This same demographic of buyer also values a polished concrete finish floor to complement the exposed wood ceiling.

This creates a significant challenge to acoustical consultants who must achieve airborne and impact sound isolation levels without the use of a resiliently mounted ceiling, or finish floor. In an attempt to quantify the isolation quality of such assemblies, a laboratory test program was completed providing sound transmission class (STC) and impact isolation class (IIC) ratings.

The baseline assembly was constructed of 300mm x 300mm (12”x12”) wood beams spaced 100 mm (48” OC), 57mm x 133 mm (nom 3”x6”) wood planks, and 19 mm x 149 mm (nom 1”x6”) wood planks laid perpendicular to the layer below. The tests that followed included use of a pre-cured independent 100mm (4”) concrete slab for ease of testing various assemblies. The slab itself was tested. The slab was installed directly above the heavy timber. A 25mm (1”) thick proprietary dimpled rubber underlayment (FF25) was installed between the slab and the heavy timber as well as a 50mm (2”) thick dimpled rubber underlayment (FF50). The results can be found in table 1.

2. LABORATORY TESTING PROGRAM

2.1 ASTM E90 Background

International building code section 1207 requires that a floor-ceiling partition separating dwellings or a dwelling and a public space meet an STC 50 based on the laboratory test procedure described in ASTM E90. Increasing mass is the most common way to achieve an increase in airborne transmission loss (TL). Doubling the mass should increase the STC by 6 dB. This is often referred to as the mass law.

2.2 ASTM E492 Background

The International building code (IBC) section 1207 requires that a floor-ceiling partition separating dwellings or a dwelling and a public space meet an IIC 50 based on the laboratory test procedure described in ASTM E492. The most common method of improving IIC is to introduce a resilient underlayment that reduces structural vibration input. A standardized tapping machine is used to hammer the floor and the sound pressure level (SPL) is measured below.

2.3 The Base Assembly

For the purpose of this paper the baseline assembly is as follows:

19 mm x 149 mm (nom 1”x6”) wood planks
57mm x 133 mm (nom 3”x6”) wood planks
300mm x 300mm (12”x12”) wood beams spaced 100 mm (48” OC)

When tested according to ASTM E90 the result was STC 29. When tested according to ASTM E492 the result was IIC 24. These results are dramatically lower than the minimum IBC requirements. The largest TL deficiencies were 6dB at 800 and 1000 Hz and the ISPL controlling frequencies were between 800-3150 with the largest 6dB deficiency at 3150 Hz. According to the mass law referenced in 2.1, if the overall mass of the assembly is doubled three times we should theoretically gain 18 dB and we will still be 3 points short of STC 50. The mass of the base assembly was 58.44 kg/m^2.

2.4 Base Assembly + 100 mm (4”) Concrete Topping

A 100 mm (4”) concrete slab was pre-constructed and cured. This independent 4” slab was then installed directly upon the base assembly. The mass of the topping slab was 223.3 kg/m^2 bringing the overall mass of the assembly to 281.74 kg/m^2. This represents 2.2 doublings of the mass. Which should give us an approximate increase in STC of 12-14 points. The resultant rating was STC 40 with control deficiencies primarily between 200 and 500 Hz.

The impact sound rating was IIC 34, representing an increase of 10 points. The control was an 8 dB deficiency at 3150 Hz. Low frequency SPL was dramatically reduced by 19 dB @ 100 Hz, 15 dB @ 125 Hz and 11 dB @ 160 Hz.

2.5 Base Assembly + 25mm (1”) FF25 + 100 mm (4”) Concrete Topping

The 100 mm (4”) concrete slab was removed and the 1” proprietary dimpled rubber underlayment (FF25) was applied above the base assembly. The concrete topping slab was then installed above the FF25. The overall mass of the assembly was increased to 293.8 kg/m^2 representing an increase of 12.06 kg/m^2. The overall rating was STC 40 with sum 32 deficiencies centered around 315 Hz (6 dB).

IIC 42 was recorded and the sum 32 rule controlled the curve with primary deficiencies between 800 and 1250 Hz. This represents an improvement of 8 dB and while low frequencies remained primarily unaffected the SPL was reduced by 18 dB @ 3150 Hz, 18 dB @ 2500 Hz and 14 dB at 2000 Hz. Mid frequency was also improved by 5-6 dB from 400-1000 Hz.

It was noted that this improvement in STC fell short of the mass law would have predicted. This indicated we likely have a “leak” in the assembly. As the test frame is less deep than the overall assembly, the upper portion of the assembly including the 4” slab and underlayment were above and not encased in the test frame. The perimeter was treated with concrete block and rubber pad to limit possible airborne sound leaks through the exposed perimeter. Based on the result we decided to retest the assembly with the concrete blocks laying flush with the side of the assembly. Resilient rubber is an effective vibration isolator but the material is permeable and therefore not an effective airborne sound barrier. The results of the retest are in 2.8 below.

2.6 Base Assembly + 50mm (2”) FF50 + 100 mm (4”) Concrete Topping

The 100 mm (4”) concrete slab was removed and the 2” proprietary dimpled rubber underlayment (FF50) was applied above the base assembly. The concrete topping slab was then installed above the FF50. The overall mass of the assembly was increased to 308.49 kg/m^2 representing an increase of 14.69 kg/m^2. The overall rating was STC 45 with sum 32 deficiencies between 125 and 400 Hz.

IIC 51 was recorded and the 8 dB rule controlled the curve at 100 Hz. This represents an improvement of 9 dB over the 25 mm interlayer. From test frequencies above 160 Hz minimum 7 dB improvements were recorded. Above 630 Hz minimum 20 dB improvements were recorded.

2.7 100 mm (4”) Concrete Slab

The base assembly was removed and the 4” concrete topping slab was installed. The airborne sound rating of STC 44 was recorded. Control frequency was an 8 dB deficiency at 500 Hz.

The IIC rating was 21 and the curve was controlled by an 8 dB deficiency at 3150 Hz.

2.8 RETEST (RT): Base Assembly + 25mm (1”) FF25 + 100 mm (4”) Concrete Topping

The 100 mm (4”) concrete slab was reinstalled above the 1” FF25 which was re-applied over the base assembly. A rating of STC 43 was recorded. Controlling frequencies were a sum 32 from 125 Hz – 500 Hz.

IIC 43 was measured with sum 32 deficiencies over a wide range from 200 – 1600 Hz.

2.9 ASTM E90 STC Figures

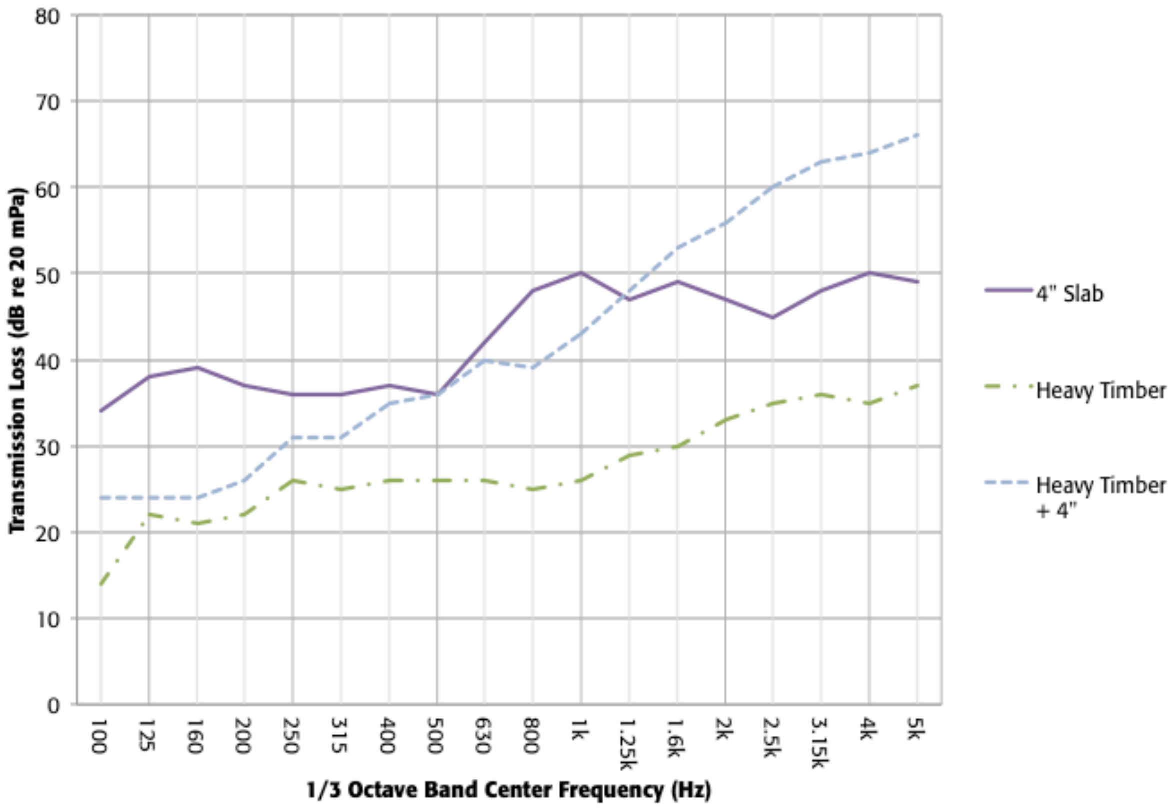

Figure 1 – TL comparison of heavy timber base assembly and its components

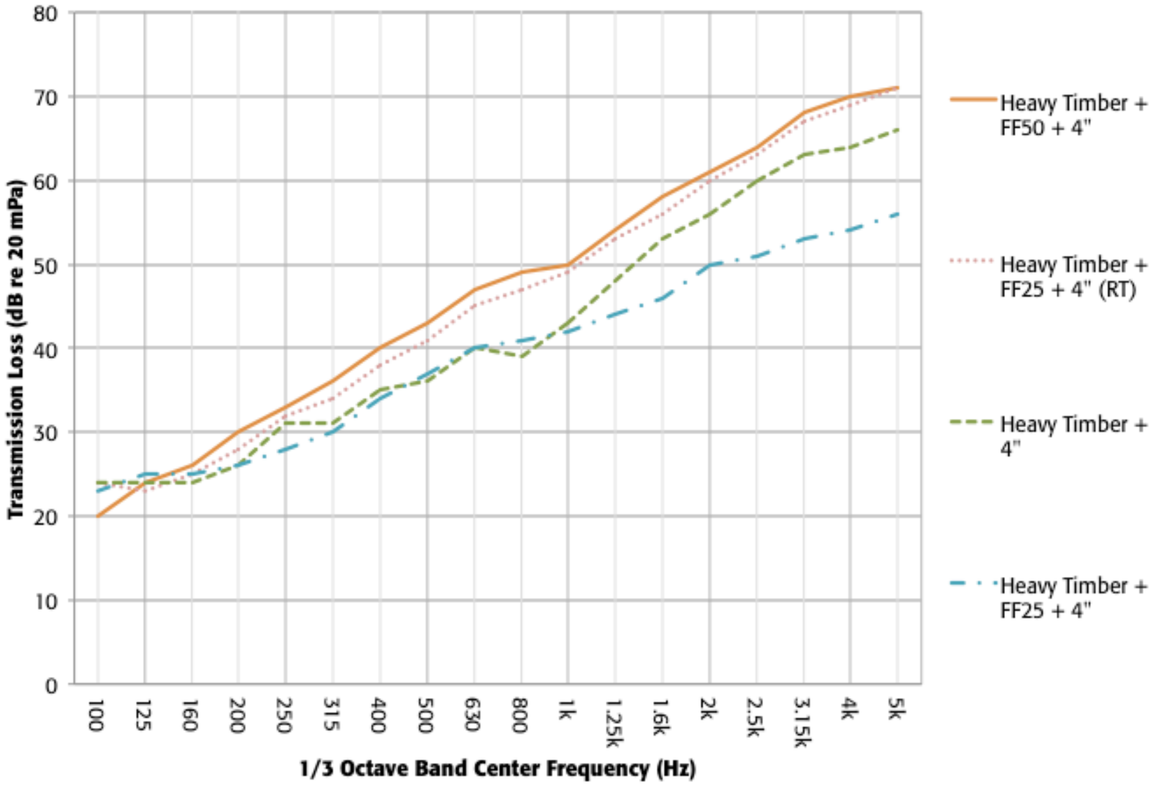

Figure 2 – TL comparison of assemblies with FF25 and FF50

2.10 ASTM E492 IIC Figures

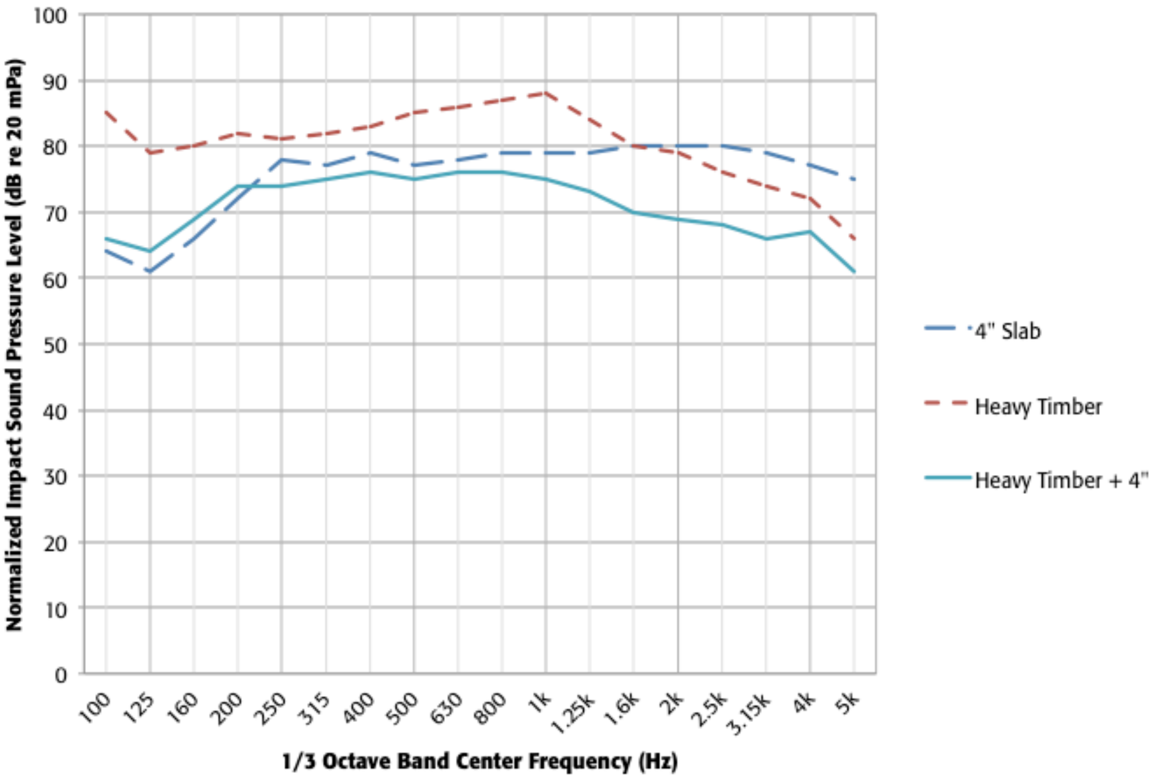

Figure 3 – NISPL comparison of heavy timber base assembly and its components

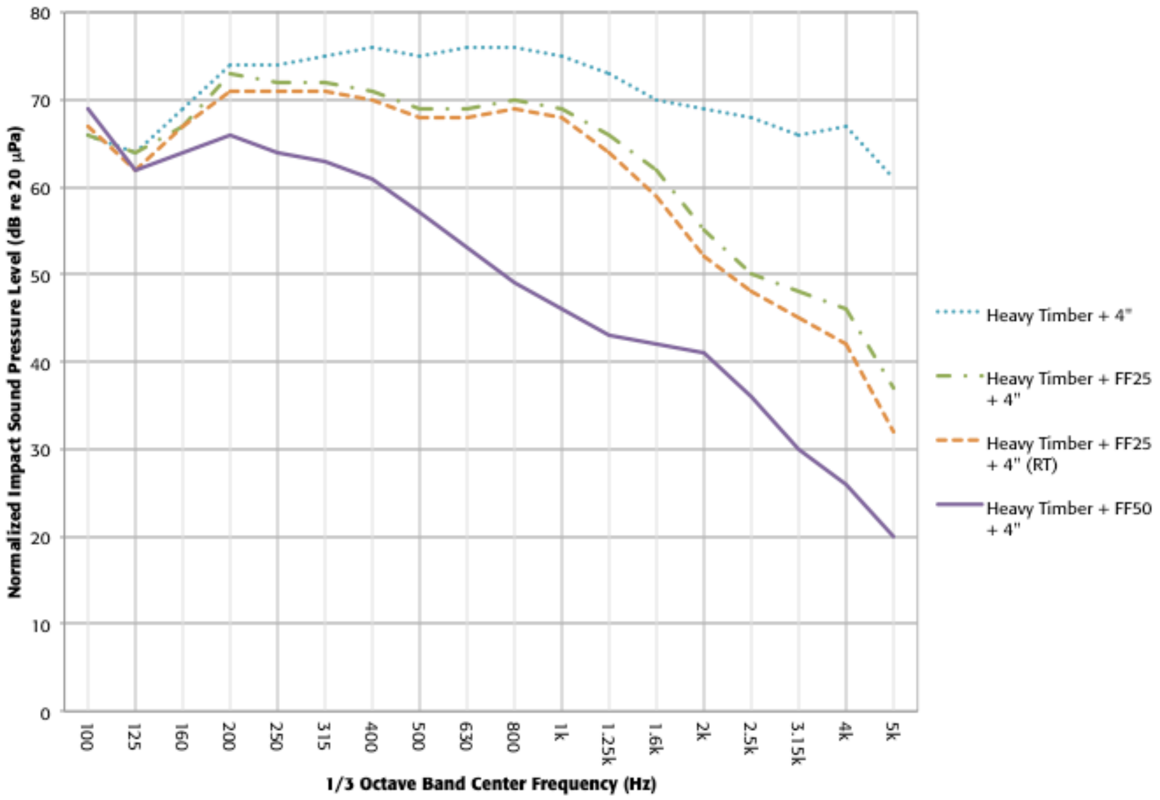

Figure 4 – NISPL comparison of heavy timber assemblies with FF25 and FF50

2.11 Tables

Table 1 – Summary of ratings and control frequencies from testing program

Assembly	STC	E90 Controlling Frequency	IIC	E492 Controlling Frequency
Heavy Timber Baseline	29	400-1600	24	630-3150
Baseline + 4” Concrete	40	160-800	34	3150
4” Concrete	44	500	21	3150
Baseline + FF25 + 4” Concrete	40	160-1000	42	200-1600
Baseline + FF25 + 4” Concrete (RETEST)	43	125-500	43	200-1600
Baseline + FF50 + 4” Concrete	45	125-500	51	100

3. CONCLUSIONS

3.1 STC performance analysis

None of the tested assemblies met the IBC section 1207 requirements for STC 50. Most interestingly, the 4” concrete slab on it’s own yielded a higher STC rating than when it was combined with the heavy timber. The additional mass and stiffness provided by combining the two masses should result in improved airborne sound isolation, but they did not (STC 44 for the concrete alone and STC 40 for the combination). Two possible causes are described below.

Between the pre-cured concrete and the heavy timber there are air pockets that cause resonance effects resulting in losses in TL. The lack of mechanical or in place curing of the concrete results in a loose connection between these rigid masses that could result in contact resonance. In a field installation when the concrete is poured on the heavy timber or underlayment, there will be continuous contact and air pockets will be eliminated. The cured bond could also limit free contact resonance, which may be present here. The FF25 and FF50 underlayment did improve STC by separating the slab and heavy timber assembly, most likely due to the resilient gap created and impedance mismatch of the materials. Air pocket resonance and free contact resonance was also reduced or eliminated due to the malleable contact between the rigid components and the softer FF25 and FF50 material.

Perimeter isolation was required in the exposed upper region of the test frame and this results in an unrealistic test condition. The test frame at NGC laboratories is limited in its ability to fully encapsulate an assembly of depth greater than approximately 300 mm (12”). When the 4” concrete slab was installed it rested completely within the test frame, whereas when the base assembly was installed, the underlayment and concrete slab were exposed above the test frame. We then rely on the ability of the lab to create perimeter isolation. This involves the use of concrete blocks and rubber strips. The STC improved by 3 dB when we altered the method of perimeter isolation of the exposed assembly. This clearly illustrates that the perimeter isolation is an acoustic leak in an airborne sound test and is limiting the performance of the assembly.

The next step is to complete field-testing of the FF50 assembly to determine if when installed in the field with a direct pour (not pre-cured) and no exposed side of the assembly we can reach the acceptable alternate ASTC 45 as described in section 1207 of the IBC. An additional floor assembly has been constructed utilizing lightweight concrete and mismatched thicknesses of FF17 and FF25 underlayment. Unfortunately this test has not been completed in time to be included in this paper.

3.2 IIC performance analysis

The lowest performance came from the 100 mm (4”) concrete. IIC 21 was measured with control frequency at 3150 Hz.

When the FF50 material was installed between the concrete and heavy timber components a rating of IIC 51 was measured which meets the requirements for IBC section 1207. The FF25 assembly performed very similarly when the method of perimeter isolation was changed indicating that for an impact sound test, the exposed upper test frame is not an issue.

The use of finish floor will significantly improve the IIC ratings of the FF25 floors. These had deficiencies above 1000 Hz where a finish floor such as vinyl plank with rubber underlayment would reduce the impact sound pressure level.

The additional floor ceiling assembly described at the end of section 3.1 will also be tested to determine if IIC 50 can be met utilizing a light weight gypsum concrete topping.

ACKNOWLEDGEMENTS

Thank you to the entire Pliteq team and the staff at NGC Laboratories.

REFERENCES

1. Paul C. Downey and Greg Bachman, “Effect of Dynamic Stiffness and Mass of Resilient Sound Mat Material on the Impact Sound Performance of Floor-Ceiling Assemblies”, Inter-Noise 2004 paper 576, (2004).

2. NGC Testing Services ASTM E492 test reports 7014076, 7014107, 7014109, 7014060, 7014108, 7014096.

3. NGC Testing Services ASTM E90 test reports 5014061, 5014080, 5014082, 5014049, 5014081, 5014072.