ICA 2019 AACHEN

PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Development of a modified impact testing method for simultaneously evaluating multiple floor toppings

Wayland DONG[1]; John LOVERDE[2]

[1,2] Veneklasen Associates, USA

ABSTRACT

Materials such as floor coverings, screeds, and resilient matting are commonly applied on top of a floor-ceiling (structural) assembly to improve the impact noise insulation. Theory and experience show that the benefit of such materials increases with frequency, with minimal effect below the natural frequency of the resilient materials and the largest effect at high frequencies. This improvement in impact insulation is added to the base performance of the structural assembly. Floor design can involve multiple parameters (finish floor, screed thickness, resilient mat thickness) even from the same manufacturer or product line, and the number of permutations rises quickly. These permutations must also be tested on multiple structural assemblies. The authors investigated a modified testing method where multiple top-side assemblies could be installed on the same structural assembly, allowing for a more efficient testing process allowing direct comparison of materials. The expectation is that airborne and low-frequency impact insulation would be consistent since the base assembly is unchanged, but high-frequency impact insulation would provide the same, consistent result as a full-scale test. Data from the investigation is presented and analyzed to validate the model and document the uncertainties.

Keywords: Low-frequency, High-frequency, Impact, Airborne, Insulation

1. INTRODUCTION

Floor coverings are materials applied on top of the base floor-ceiling assembly that are not used to meet structural or fire resistance requirements. Floor coverings primarily include finish floors, screeds, and resilient materials designed for impact noise isolation, but also include materials for thermal control, waterproofing, leveling, etc. A common class of product for improving impact insulation is resilient matting installed either below the finish flooring or below a gypsum concrete screed. Many products can be installed with a wide variety of finish floors and structural systems, and the product must be tested in the laboratory with multiple finish floors and on all of the structural assembly types that may be encountered. The number of combinations quickly rises to unmanageable quantities.

Here we begin development of a modified test method in which the floor surface is divided into zones, enabling testing of multiple floor toppings on the same structural assembly. This will significantly reduce the time and cost required to assembly the necessary data, with the supposition that the results will provide the same information. In this paper, we explain why the modified method is expected to yield similar results as full floor testing, and begin testing to validate the method.

2. ANALYSIS

It is well documented that the improvement in impact insulation due to floor coverings is approximately zero below the resonance frequency of the floor covering, and increases with frequency above the resonance frequency (1–3). In other words, there are two frequency domains that are relevant to the impact insulation of an assembly. At low frequencies (below the resonance frequency of the floor covering), the isolation is determined by the properties of the structural system and the floor covering can largely be ignored. At high frequencies, the minimum level of isolation is

---

[1] wdong@veneklasen.com

[2] jloverde@veneklasen.com

determined by the base assembly, but the impact insulation is determined largely by the properties of the floor covering.

Because the low and high frequency domains are due to different physical processes, the testing program can be optimized to obtain the desired acoustical information with increased efficiency.

2.1 Rating for low-frequency impact noise

The authors have shown that the low-frequency impact isolation can be characterized by the levels in the 50, 63 and 80 Hz bands generated by the standard tapping machine (4,5). The rating for measuring low-frequency impact isolation in the field called Low-frequency Impact Rating (LIR) and is calculated by

$$LIR = 190 - 2L_{50-80} \tag{1}$$

where L_{50-80} refers to the energetic sum of the impact sound pressure levels in the 50, 63, and 80 Hz third-octave bands. For assemblies controlled at low frequencies, this rating is well correlated with $L'_{nT,w} + C_{I,50-2500}$, which is the recommended metric in the COST Action (6), and the recommended classification schemes for the LIR are also consistent with the COST Action guidelines (7).

Although originally intended for field testing, the same rating can be applied to any measurement of impact sound pressure levels at the appropriate frequency bands, including laboratory testing. When calculated using normalized levels measured in the laboratory per ASTM E492 (8), the rating is named Low-frequency Impact Insulation Class (LIIC) and is calculated in the same manner:

$$LIIC = 190 - 2L_{50-80} \tag{2}$$

The measurement uncertainty increases at low frequencies, and the reproducibility between laboratories at those frequencies is expected to be poor. The statistics of LIIC have been investigated (9). Important conclusions from the previous study include confirming that the finish flooring did not appear to have any effect on the LIIC rating, and measuring the standard deviation of LIIC in the same chamber to be around 2–4 points (depending on the assembly). While this variation is sizable, the study also confirmed that by averaging a sufficient number of tests, even small differences between assemblies (on the order of a few dB) could be accurately measured.

2.2 Rating for high-frequency impact noise

Impact noise at high frequencies depends strongly on the local compliance of the surface that is struck by the falling hammer (10). The resultant behavior is that the improvement in impact insulation level (ΔL_n) due to floor coverings is

$$\Delta L_n = K \lg \frac{f}{f_0} \tag{3}$$

where f is the frequency, f_0 is the resonance frequency of the floor covering, and K is a constant (typically 30 or 40) that depends on the type of covering and how it is coupled to the structure (1–3). The resonant frequencies of available floor coverings varies widely, but the authors have shown that evaluation of the high-frequency impact isolation can be evaluated by including the bands from 400 Hz and above (4). Even for materials that have resonance frequencies below 400 Hz, the improvement in those bands is small compared to higher frequency bands. Ratings such as IIC and $L_{n,w}$ become controlled by lower frequency bands, and therefore do not accurately describe the amount of high frequency isolation that the assembly provides.

The authors have therefore proposed a new family of high-frequency impact ratings that are intended to accurately portray the effect of floor coverings. The calculation procedure is the same as the IIC rating, except that the frequency range is from 400–3150 Hz, and the 8 dB rule is not implemented. There is a high-frequency version of each of the existing ratings; the laboratory rating is High-frequency Impact Insulation Class (HIIC).

For most floors with ratings below IIC 55 ($L_{n,w}$ above about 55), the HIIC and the IIC are usually the same. For high-performing floors with high-performing floor coverings (i.e., with low resonance frequencies), however, the HIIC can greatly exceed the IIC. Consider the numerous case studies in which floors with insufficient high-frequency impact insulation were successfully mitigated with changes to the assembly (7,11). In these assemblies, the HIIC ratings increase dramatically (15-20 points) along with subjective reaction, while IIC ratings remain nearly unchanged.

2.3 Rationale

Based on this behavior, we consider the feasibility that installing multiple floor coverings on the same structural assembly would result in the same low and high-frequency impact ratings as the full installation.

For low frequency measurements, the floor covering has minimal effect. If multiple floor coverings are installed on the same assembly, measurement of the low frequency impact insulation should yield the same result when measured on any of them. This is complicated by several factors. The uncertainty in measurement of LIIC is large, so that only the average of several tests is meaningful. Further, the noise level can vary with tapping machine location, and the locations will in general be different with multiple floor coverings as oppose to a single one. Since the result is averaged over tapping machine positions, however, the low frequency rating on average should be the same whether measured over single or multiple floor coverings.

For high frequency measurements, for "locally reacting" floor coverings, the specimen size is not important by definition. For floating floor coverings, the specimen needs to be of sufficient size that the response to the tapping machine is the same as the full floor installation. For example, it is generally assumed that the laboratory (full floor) installation of approximately 10 m^2 is representative of field conditions where the floor area may be much larger. ISO 10140-1 (12) Annex H allows floor covering measurements to be made on 3 or more small specimens (large enough only for a single tapping machine position), and 10140-5 (13) Annex G allows lightweight wood floor mock-up that is 2.0 x 2.6 m (5.2 m^2). However, it remains for experiment to determine the differences between full floor installations and smaller areas.

For airborne isolation, the floor covering would be expected to have an impact if it changes the mass of the assembly. If multiple floor coverings are tested simultaneously, the airborne isolation should be similar to the full floor installation if each covering has similar mass. In other words, all of the floor coverings installed should be of the same type.

3. Proposed Method

The proposed method is internally referred to as "Floor Zone". The structural assembly is built and installed in the test opening in the usual fashion. The top surface of the structural assembly is divided into zones. Multiple configurations are possible; here we consider dividing the floor into 4 equal zones (quadrants).

The laboratory in which this was tested has total specimen area of 10.98 m^2. The zones are separated by 2x4 lumber (approximate dimensions 38 x 89 mm). The lumber borders are lined with perimeter isolation material in the same manner as the perimeter of the specimen. The size of the resultant zones is 1473 mm x 1778 mm (2.62 m^2). See Figure 1.

Four impact tests are performed, with four tapping machine positions on each zone. The tapping machine positions are as defined in ASTM E492 (8), except oriented based on the center of each zone rather than the center of the entire floor area. The receiving room microphone positons and measurement procedure is the same as for an full floor installation. Airborne testing is also performed in the same manner as if the installation were the full floor.

Figure 1 – A picture of the top surface of the assembly divided into 4 Floor Zones. A different floor topping will be installed in each Floor Zone.

4. Evaluation

The Floor Zone concept has been tested on a wide variety of base structural assemblies, including concrete slabs, wood and steel trusses, timber joists, wood I-joists, and cross-laminated timber. Here we present the data for tests using wood open web trusses, 457 mm (18 in.) deep, with fiberglass insulation, 19 mm (3/4 in.) oriented strand board subfloor, and one layer of 16 mm type C gypsum board ceiling on resilient channel. All of the assemblies tested included a gypsum concrete screed (various thicknesses), with a variety of sound mats both above and below the screed. Finish floors included none (bare gypsum concrete), several luxury vinyl plank floors, engineered wood, ceramic tile, and carpet. Over 30 full floor installations were measured and over 20 Floor Zone installations with four floor coverings each.

4.1 Airborne

Histograms of the STC ratings for full installation versus Floor Zone (FZ) is shown in Figure 2. Almost all of the full floor installations used 25 mm (1 in.) gypsum concrete screeds. The Floor Zone toppings sometimes varied the gypsum concrete thickness from 19 mm (3/4 in.) to 38 mm (1.5 in.), but the average over the floor was a similar total weight. Therefore it is not surprising that the airborne isolation tests do not show any difference between full installation and Floor Zone.

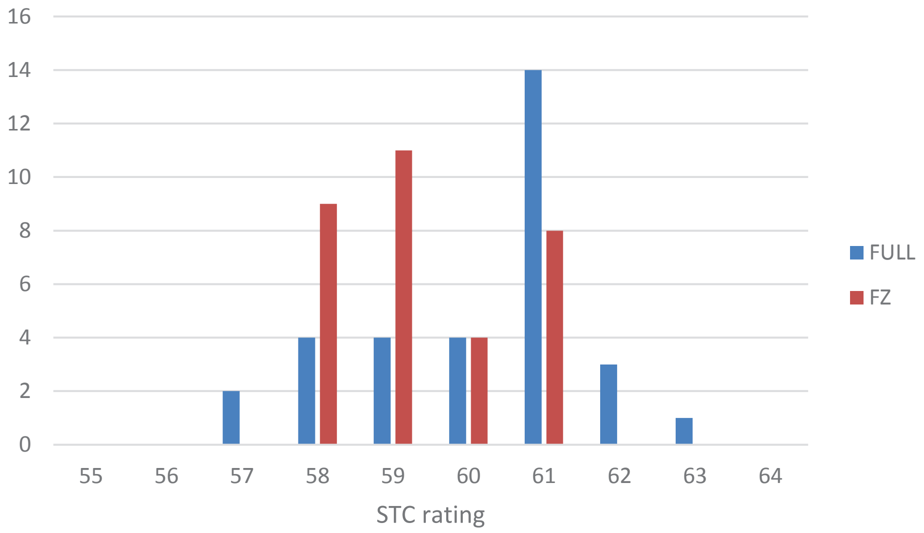

Figure 2 – Histogram of STC ratings for full installation vs. Floor Zone

4.2 Low-frequency impact

The statistics of LIIC ratings is shown in Table 1 and Figure 3. There was no apparent difference in the low frequency rating of this assembly with changes in floor topping. That is, selecting subsets of the tests with specific flooring or matting types or gypsum concrete thickness did not affect the average or the width of the distribution. This confirms the previous study (9).

Table 1 – LIIC statistics for open web truss assemblies

	Full floor	Floor Zone
Count	23	83
Mean	56.5	55.4
Standard deviation	3.2	4.6

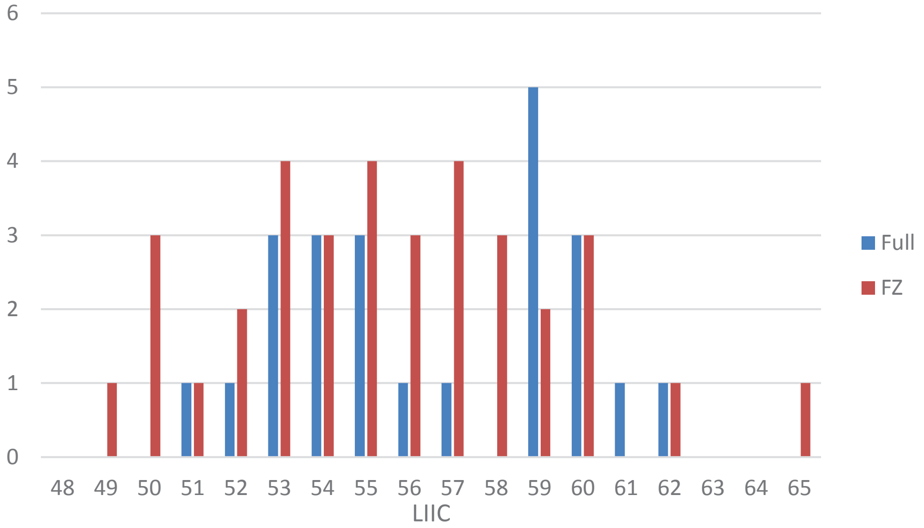

Figure 3– Histograms of LIIC ratings for full installation vs. Floor Zone

The spread of the data is wider with the Floor Zone compared to full floor installations. Some of the variation may be attributed to tapping machine position, which are closer to one corner for the Floor Zone testing. However, there is no apparent bias in the average LIIC of each quadrant and the overall average. Therefore, the LIIC ratings for the zones can be averaged to obtain a measurement of the LIIC of the structural system, irrespective of finish floor.

4.3 High-frequency impact

Confirmation that the high frequency impact ratings were similar between full floor and Floor Zone installation proved to be more difficult than expected. The issue was that even though all of the testing was performed in the same lab, the repeatability between different tests of the same assembly was poor. For example, the two tests shown in Figure 4 and Table 2 have identical descriptions and were tested in the same lab less than one year apart. Both assemblies are full floor installations with no finish floor.

Table 2 – Single number impact ratings for nominally identical assemblies

	Test A (blue)	Test B (red)
IIC	53	55
LIIC	62	56
HIIC	52	56

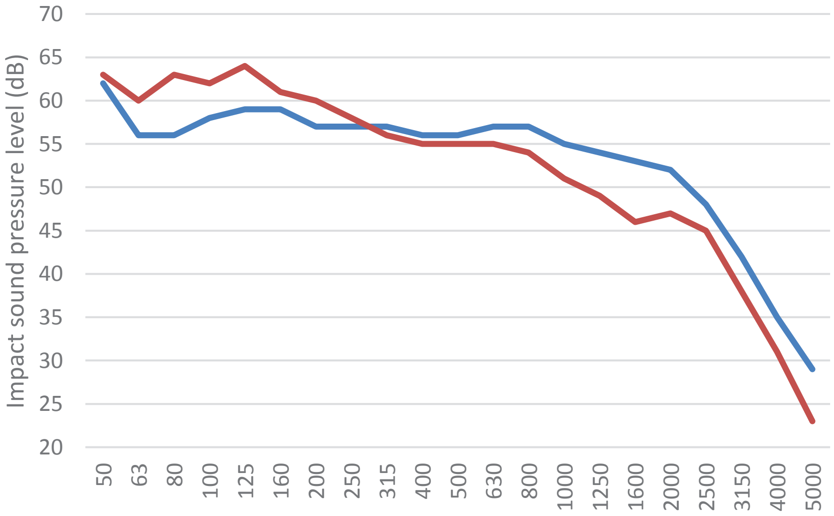

Figure 4 – Impact spectra for nominally identical assemblies

The authors have measured the variation in “rebuild repeatability” before (14,15). Uncertainties of this magnitude require averaging a large number of tests to evaluate the difference between full floor and Floor Zone testing. Without a very large number of tests, it is difficult to separate the differences between floor coverings from the uncertainty in the overall test method. As an indication, Table 3 and Figure 5 are a subset of the open web truss data; the tests on the left have no finish floor while the tests on the right have an engineered wood finish floor. The Floor Zone tests shown are not from different quadrants of the same test; they are of single quadrants of different tests that had the same floor topping.

From this data, the variation between Floor Zone tests of the same assemblies is not any larger and may be smaller than the variation between full floor tests of the same assemblies. There remains variation between the Floor Zone tests and the full floor tests. However, this variation does not appear to be any larger than the variation between full floor tests, i.e., between the uncertainty in the measurement method.

Table 3 – Single number ratings for nominally identical assemblies

	Full (blue solid)	Full (blue dash)	Floor Zone (red solid)	Floor Zone (red dash)	Full (blue)	Floor Zone (red solid)	Floor Zone (red dash)	Floor Zone (red dot-dash)
IIC	53	55	57	58	57	54	57	55
LIIC	62	56	60	63	53	49	53	49
HIIC	52	56	57	58	63	59	58	58

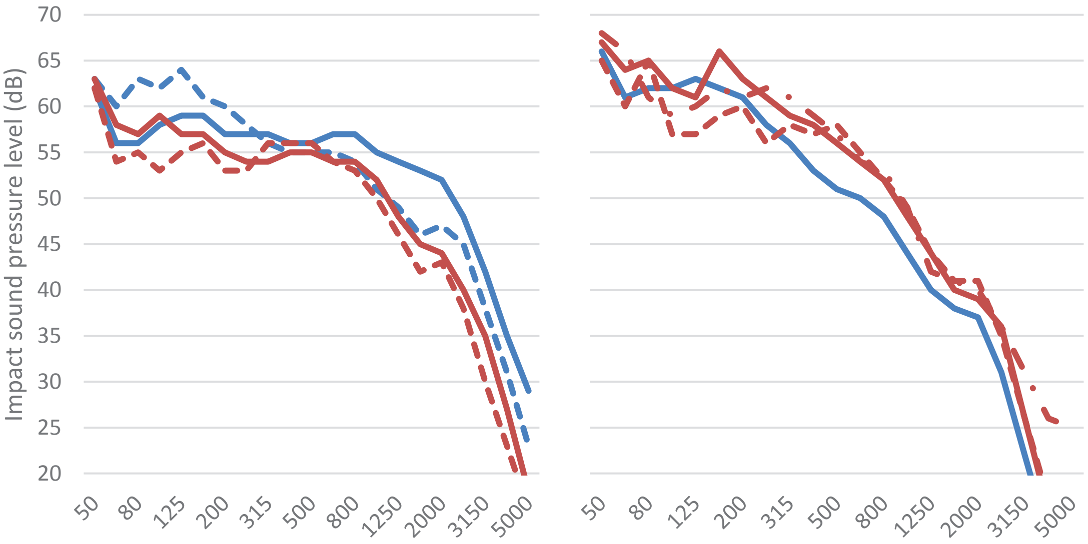

Figure 5 – Impact spectra of tests shown in Table 3. Full floor tests are blue and Floor Zone are red.

5. SUMMARY

A method (Floor Zone) has been developed to measure multiple floor coverings on the same assembly. As expected, the division of the floor covering does not affect the airborne noise isolation or the low frequency impact noise isolation of the assembly. The exact relationship between the full floor and Floor Zone tests for the broadband and high-frequency impact noise ratings is currently undetermined due to the large uncertainty and poor repeatability of the measurement method, which was anticipated. This investigation shows that the Floor Zone method is viable and does not show a significant reduction in accuracy from the Full Floor method. The adoption of the method does not appear to negatively affect the measurement limitations.

Although not the purpose of the modified method, this testing also provides confirmatory evidence to the theoretical expectations that low frequency impact noise is determined by the structure, while the high frequency noise is largely determined by the reduction in impact noise provided by the floor covering. That is, evaluation, prediction, and design of impact noise isolation should occur in two independent frequency domains, which has been proposed as a means to evaluate impact noise (4).

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of USG Corporation in the gathering of this data and include Mr. Brett Fleury, Mr. Alex MacDonald, Mr. Randy Mullett, Mr. Ray Kaligian and Mr. Phil Ciesulka as being instrumental in this work. The authors also wish to thank the continued support of the Paul S. Veneklasen Research Foundation and Veneklasen Associates, Inc.

REFERENCES

1. Vér IL. Impact Noise Isolation of Composite Floors. J Acoust Soc Am. 1971 Oct 1;50(4A):1043–50.
2. ISO 12354-2. Building acoustics - Estimation of acoustic performance of buildings from the performance of elements Part 2: Impact sound insulation between rooms.
3. Rindel JH. Sound Insulation in Buildings. CRC Press; 2018.
4. LoVerde JJ, Dong DW. A dual-rating method for evaluating impact noise isolation of floor-ceiling assemblies. J Acoust Soc Am. 2017 Jan 1;141(1):428–40.
5. LoVerde J, Dong W. The low-frequency limit of proposed ratings for quantifying low-frequency impact insulation. Proc Meet Acoust. 2018 Nov 5;35(1):015003.
6. Rasmussen B, Machimbarrena M. COST Action TU0901 - Building acoustics throughout Europe. Volume 1: Towards a common framework in building acoustics throughout Europe. COST Office Action TU0901; 2014.
7. LoVerde J, Dong W. Developing classifications using a dual-rating method of evaluating impact noise. In: Proc INTER-NOISE 2018. Chicago, IL; 2018.
8. ASTM Standard E492, "Standard Test Method for Laboratory Measurement of Impact Sound Transmission Through Floor-Ceiling Assemblies Using the Tapping Machine." ASTM International; 2009.
9. LoVerde J, Dong W. Laboratory measurement of low-frequency impact sound. In: Proc ICSV25. Hiroshima; 2018.
10. Watters BG. Impact-Noise Characteristics of Female Hard-Heeled Foot Traffic. J Acoust Soc Am. 1965;37(4):619–30.
11. LoVerde J, Dong DW. Optimizing floor-ceiling assemblies in wood-framed multifamily buildings using a two-rating method of evaluating impact isolation. In: Proc ICA2016. Buenos Aires, Argentina; 2016.
12. ISO 10140-1 (2016), Acoustics - Laboratory measurement of sound insulation of building elements Part 1: Application rules for specific products. International Standards Organization; 2016.
13. ISO 10140-5, Acoustics - Laboratory measurement of sound insulation of building elements Part 5: Requirements for tests facilities and equipment. International Standards Organization; 2010.
14. LoVerde J, Dong DW. Addressing the lack of statistical control in acoustical testing laboratories. J Acoust Soc Am. 2017 May 1;141(5):3929–3929.
15. Dong W, LoVerde J, Holmgreen E, Bergquist S. Investigation of Extended Repeatability Conditions in Laboratories. In: Proc ICSV25. Hiroshima; 2018.