DOI: 10.61782/fa.2023.1212

DESIGN OF FLOOR-CEILING ASSEMBLIES USING DUAL RATINGS OF IMPACT NOISE INSULATION

John LoVerde[1] **Wayland Dong**[2]* **Samantha Rawlings**[1]
[1] Veneklasen Associates, Santa Monica, California, USA
[2] Paul S. Veneklasen Research Foundation, Santa Monica, California, USA

ABSTRACT

New ratings to evaluate impact noise insulation have recently been published as ASTM standards, which are commonly used to evaluate building acoustics measurements in North America. ASTM E3207 defines new ratings for low-frequency impact insulation, defined by the 50-80 Hz third-octave bands. ASTM E3222 defines new ratings for high-frequency impact insulation, defined by the 400-3150 Hz bands. These ratings are based on the two-rating method of evaluating impact noise isolation proposed by the authors [1] and have been used for many years prior to publication. Some have objected that dual ratings are not necessary to assess code compliance or predict subjective reaction. These points are debatable, but such convenience is not the primary benefit of a dual rating system. The physics of impact noise generation is different in the two frequency domains, and therefore impact insulation in the two frequency domains requires different designs, products, and strategies. Using separate ratings provides value and design information that is obscured with single ratings. Examples illustrating these points are presented.

Keywords: impact insulation, dual ratings, low-frequency impact, high-frequency impact

1. INTRODUCTION

Most current classifications for impact noise insulation in multifamily housing are based around Impact Insulation Class (IIC) per ASTM E989 [2] or $L_{n,w}$ per ISO 717-2 [3]. These ratings are nearly equivalent and are based on the impact noise level generated by the standard tapping machine in third-octave bands from 100–3150 Hz. The existing ratings are insufficient to describe impact insulation and do not adequately correlate with subjective reaction [4], [5]. On the one hand, impact noise below 100 Hz is clearly important for evaluating human reaction [6], [7], which has led to various methods to include these frequencies in the rating, most notably the spectrum adaptation terms in ISO 717-2. On the other hand, while it is often assumed that the existing ratings are suitable for high-frequency isolation, the existing ratings are often controlled by frequency bands that do not describe the high-frequency performance of the assembly.

To address these concerns, the authors have proposed that impact noise occurs independently in two frequency domains [1]. Both sets of new ratings are based on the existing laboratory and field measurement methods without modification (except for frequency range), and both can be calculated from existing test data.

1.1 New ASTM Ratings

The new low-frequency ratings are defined in ASTM standard E3207-21 [8]. For field measurements, the rating is called Low-frequency Impact Rating (LIR) and is calculated by

$$LIR = 190 - 2L_{50-80} \quad (1)$$

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. LIR is defined only for the non-normalized impact sound levels. The same calculation can be applied to the normalized

*Corresponding author: wdong@veneklasen.com

sound pressure levels generated by laboratory impact insulation testing, in which case the rating is named Low-frequency Impact Insulation Class (LIIC).

The new high-frequency ratings are defined in ASTM standard E3222-20 [9]. Just as with the existing ratings, the calculation method describes a family of ratings depending on whether the third-octave data was acquired in the laboratory or the field, or what normalization was used. See Table 1.

By intent, the high-frequency ratings are the same as the existing ratings except for the frequency range. The rating is calculated using third-octave impact sound pressure level data and a reference curve in the same manner as the existing IIC and $L_{n,w}$ ratings. The reference curve is the same as the existing contour, except that it includes only the bands from 400 to 3150 Hz. The method of calculating the rating is also the same, with the maximum total deficiencies remaining at 2 per band (20 total). The 8 dB rule is not implemented.

Rating	Name	Field or Lab; Normalization	Existing Ratings
HIR	High-frequency impact rating	Field Non-norm	ISR L'_{w}
NHIR	Normalized HIR	Field $T_0 = 0.5$ s	NISR $L'_{nT,w}$
AHIR	Absorption-normalized HIR	Field $A_0 = 10$ m^2	AIIC $L'_{n,w}$
HIIC	High-frequency impact insulation class	Lab $A_0 = 10$ m^2	IIC $L_{n,w}$
ΔHIIC	Improvement in HIIC	Lab $A_0 = 10$ m^2	ΔIIC ΔL_{w}

Table 1: New family of high-frequency impact ratings per ASTM E3222, showing normalization and correspondence with existing ratings

1.2 Response

The response to the new ratings has varied considerably. Many manufacturers of flooring and underlayment products were quick to start publishing the high-frequency ratings, noticing that they better described the performance of their products. Others, however, have commented that using two ratings is not necessary to evaluate compliance with impact noise requirements.

While we do not necessarily agree with these comments, the benefits of a two-rating method go beyond convenience. In this paper we attempt to describe how using a two-rating method clarifies how we think about impact insulation and greatly improves how we evaluate and design floor-ceiling assemblies.

2. TWO FREQUENCY DOMAINS OF IMPACT SOUND

2.1 Theoretical expectations

In simple lumped-element models of impact noise developed long ago [10]–[12], there is a natural division of the generated vibration into low- and high-frequency domains, based on the compliance of the floor surface. For example, Figure 1 reproduces Fig 2c from Ref [11] which is the modeled force spectrum of the tapping machine hammer on a floor. There is a qualitative difference in the behavior in the two frequency domains, and the demarcation frequency ω_0 is determined by the local compliance of the surface.

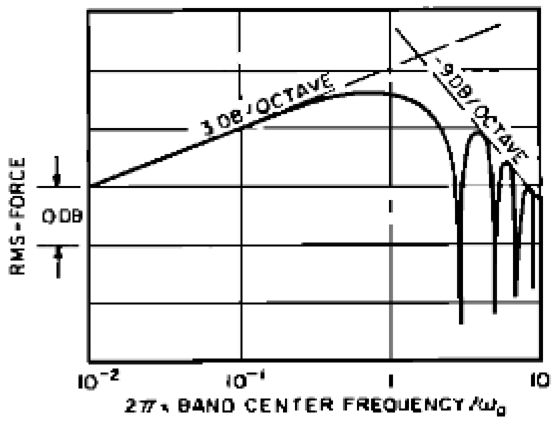

Figure 1: Reproduction of Figure 2c of Ref [11] showing the modeled force spectrum from tapping machine hammer impacts. The division into low- and high-frequency domains is evident.

In the low-frequency domain, the impact of the hammer of the tapping machine is short relative to the period of vibration. In this domain, the behavior can be explained by the momentum transfer between the hammer and the assembly; this is determined by the mobility of the structure, and the floor covering is unimportant. To put it another way, the low frequency force is proportional to the impulse (area under the curve of the force pulse in the time domain), and the detailed shape of the force pulse is unimportant.

The high-frequency response is determined by the local compliance of the floor at the hammer location. As Watters emphasizes, resilient floor coverings do not isolate the floor system from vibration, but reduce the impact force generated at those frequencies [11]. From this, the reduction in impact noise due to floor covering (i.e., compared to the bare structure) can be shown to follow a simple power law with respect to frequency; that is,

$$\Delta L_n = \begin{cases} K \lg \frac{f}{f_0}, f > f_0 \\ 0, f < f_0 \end{cases} \quad (1)$$

where ΔL_n is the reduction in impact sound level at frequency *f*, f_0 is the resonance frequency of the floor covering, and K is a constant (often taken to be 40). This behavior is well known for concrete structures and included in standard calculation methods [13], but this can also be shown [14] to accurately describe the observed behavior of lightweight joist-framed floor-ceiling assemblies.

The frequency ranges of the new rating methods were developed empirically based on field testing. The frequency ranges are wholly consistent with the theoretical expectations. The resonance frequency of the floor covering commonly used (in the North American market) is typically around a few hundred Hertz, and this was the basis of the frequency range of the high-frequency ratings [1].

Using a dual-rating method for evaluating impact insulation is useful because it matches the physics of the problem. Because there are different physical phenomena in play for low and high-frequency impact noise, it is natural to expect that the design, mitigation and evaluation of impact noise will be different in these two domains.

2.2 Subjective Reaction

Although studies have shown that low-frequency impact noise is crucial to subjective reactions [7], experience has shown that occupants distinguish between low- and high-frequency impact sound. The authors have previously described a study where the low-frequency impact noise was mediocre yet the occupant complaints decreased as the high-frequency rating increased [15]. Additional studies reported in [16] documented several projects where the high-frequency ratings were improved while the low-frequency ratings remained largely unchanged. The improvements in high-frequency ratings were correlated with positive evaluation by the residents.

It therefore appears that occupants can evaluate the performance in one frequency domain independently of the other.

3. DESIGN USING TWO RATINGS

3.1 Classifications with Single Ratings

It will always be possible to establish a single rating that can enforce minimum performance in both frequency domains. As a trivial example, a minimum function can combine multiple ratings into a single number, so that requiring that $\min(LIR, HIR) > 50$ has the same effect as separately requiring $LIR > 50$ and $HIR > 50$. Such an artificial rating system is not a simplification but obscures the physics of the problem. This does not provide any benefit but can lead to misunderstandings.

In our opinion, the differences in perception, design, and mitigation of low- and high-frequency impact insulation are so different that attempting to combine them into a single rating is counterproductive. There is no more benefit to combining LIR and HIR than there is to combining STC and IIC. Obviously three rating requirements (airborne, low-frequency impact, high-frequency impact) are more complicated than two (airborne and impact). However, the additional complication is not undue but is well warranted since it improves the description of the assembly.

In our opinion, this argument is moot because there is no single number rating that can adequately describe the range of real-world impact isolation. The observed variation in actual field testing is of the order of 60 points in both high- and low-frequency ratings, and there is minimal correlation between them [1]. It may be possible to use single ratings for subsets of the data. For example, the authors previously examined typical German floor assemblies [14] and found that they mostly had very good high-frequency impact insulation. For these assemblies, the high-frequency insulation is good enough and only the low-frequency issue remains to be solved, and the problem has been reduced to a single dimension. Conversely, concrete high-rise buildings have good low-frequency impact insulation, and the problem is reduced to the single dimension of the high-frequency impact insulation. Considering buildings of a particular construction type, e.g., common in a particular country or region, it may be possible to develop a single rating that can rate the floors. However, when considering the general problem, and considering the range of independent variation in low- and high-frequency response, two ratings will be required to adequately describe the performance.

3.2 Specifying Floor Coverings

Consider the example discussed in Ref. [1], which it must be emphasized is not a cherry-picked example but a common experience in multifamily floor design. Figure 2 shows the averaged impact spectra for flooring products in a building with and without a resilient matting. As might be expected, the floors with resilient matting were clearly preferred to floors without, and this is obvious from examination of the spectra. However, the existing ratings for these floors, including NISR, $L_{nT,w}$, and $L_{nT,w} + C_{I,50-2500}$, are almost identical. This illustrates the difficulty in developing a single-number rating for this type of spectrum. Any single rating that includes the lower frequencies, which it must as these are important to subjective reaction, will tend to be controlled by those frequencies, which makes it insensitive to large and important changes at the high frequencies.

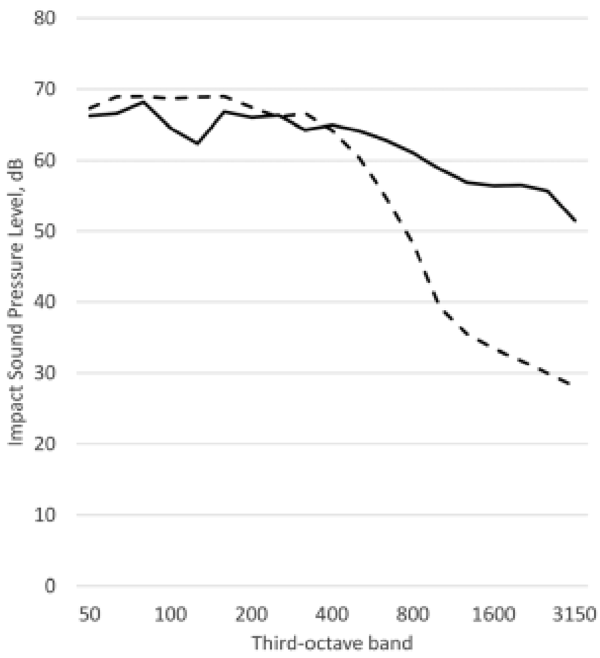

Figure 2: Impact spectra from the building discussed in the text. Same as Fig. 8a from Ref. [1]

This example was a condominium, which is one class of projects (others include hotels and schools) where the finish flooring is regularly replaced, and the performance of the flooring needs to be evaluated and regulated. The above example is a typical older, wood joist building with poor performance at low frequencies, but where the occupants still wish to require flooring products that achieve a level of performance regarding high-frequency sources. The existing ratings did not accurately describe the floors and did not provide a method of evaluating other flooring products. The HIR ratings of these floors varied by 10 points, which much more accurately characterizes the performance of the floor.

3.3 Specifying Flooring

It has long been a problem in the flooring and resilient underlayment industry to differentiate between high-performing floor coverings. The IIC rating of a floor rarely exceeds 60. The customer, not having technical knowledge of impact ratings, assumes that products can be compared by their IIC ratings, but products with the same IIC rating (even on the same base structural assembly) can vary at the high frequencies by over 10 points. Using the HIIC and ΔHIIC ratings instead of IIC and ΔIIC will greatly clarify the situation. Products can be accurately rank-ordered and cost-benefit decisions can be made more accurate. We have shown that in most cases, the rank-ordering of products using HIIC rating can be made relatively independently of the structural system [17].

3.4 Comparing Structural Systems

The low-frequency ratings can be used to evaluate the performance of floor assemblies, and to predict the likelihood of complaints from thudding.

The primary factor affecting LIR is the structural system. Much work remains in order to be able to predict, for example, the LIR of a system based on structural design or laboratory testing. However, current work has shown that LIIC is a useful design tool for comparing the effect of changes to the design within a given laboratory. For example, we have determined that an 8-inch (200 mm) concrete slab is 5 LIIC points better on average than a 6-inch (150 mm) slab. In contrast, adding a ceiling to a concrete slab, while it greatly improves the impact insulation at most frequencies, has no measurable effect on the LIIC [18]. Different brands of resilient channel can account for 7 LIIC points difference between wood truss assemblies [19].

4. SUMMARY

New ASTM ratings have recently been introduced for low- and high-frequency impact insulation. Experience with these ratings has shown the value of two-rating systems where separate frequency ranges are evaluated independently. Impact noise is generated and controlled differently in different frequency ranges, and using separate ratings clarifies the problem and encourages better physical understanding. Given a pair of ratings, the designer immediately knows whether the floor requires attention to structural or ceiling changes, or to the floor coverings. Specifying and comparing the relevant products is also much easier with two ratings. The ratings are a better method to design and evaluate impact insulation, while facilitating both internal design discussions and communication with non-experts.

5. ACKNOWLEDGMENTS

Thanks to our colleagues at Veneklasen Associates for their longstanding support. Funding provided by the Paul S. Veneklasen Research Foundation.

6. REFERENCES

[1] J. J. LoVerde and D. W. Dong, "A dual-rating method for evaluating impact noise isolation of floor-ceiling assemblies," *J. Acoust. Soc. Am.*, vol. 141, no. 1, pp. 428–440, Jan. 2017, doi: 10.1121/1.4973868.

[2] "ASTM Standard E989-06, Standard Classification for Determination of Impact Insulation Class (IIC)," ASTM International, 2006.

[3] "ISO 717-2 (2013), Acoustics - Rating of sound insulation in buildings and of building elements Part 2: Impact Sound Insulation," International Standards Organization, 2013.

[4] W. E. Blazier and R. DuPree, "Investigation of low-frequency footfall noise in wood-frame, multifamily building construction," *J Acoust Soc Am*, vol. 96, no. 3, p. 1521, 1994, doi: 10.1121/1.410230.

[5] T. Mariner and H. W. Hehmann, "Impact-Noise Rating of Various Floors," *J Acoust Soc Am*, vol. 41, no. 1, p. 206, 1967, doi: 10.1121/1.1910319.

[6] V. Belmondo, T. Heebink, and F. Brittain, "Ranking the Impact Sound Transmission of Wood-Framed Floor-Ceiling Assemblies," *J Acoust Soc Am*, 1974.

[7] B. Rasmussen and M. Machimbarrena, "COST Action TU0901 - Building acoustics throughout Europe. Volume 1: Towards a common framework in building acoustics throughout Europe," COST Office Action TU0901, 2014.

[8] "ASTM E3207-21, Standard Classification for Determination of Low-frequency Impact Noise Ratings," ASTM International, 2021. doi: 10.1520/E3207-21.

[9] "ASTM E3222-20, Standard Classification for Determination of High-frequency Impact Sound Ratings," ASTM International, 2020. doi: 10.1520/E3222-20.

[10] L. Cremer, M. Heckl, and B. A. T. Petersson, *Structure-Borne Sound: Structural Vibrations and Sound Radiation at Audio Frequencies*, 3rd ed. Berlin Heidelberg: Springer-Verlag, 2005. Accessed: Apr. 10, 2018. [Online]. Available: //www.springer.com/gp/book/9783540226963

[11] B. G. Watters, "Impact-Noise Characteristics of Female Hard-Heeled Foot Traffic," *J Acoust Soc Am*, vol. 37, no. 4, pp. 619–630, 1965.

[12] I. L. Vér, "Impact Noise Isolation of Composite Floors," *J. Acoust. Soc. Am.*, vol. 50, no. 4A, pp. 1043–1050, Oct. 1971, doi: 10.1121/1.1912726.

[13] "ISO 12354-2. Building acoustics - Estimation of acoustic performance of buildings from the performance of elements Part 2: Impact sound insulation between rooms."

[14] J. LoVerde, W. Dong, and J. Scheck, "Ratings and classifications for high-frequency impact noise isolation," 2019.

[15] J. LoVerde and D. W. Dong, "Optimizing floor-ceiling assemblies in wood-framed multifamily buildings using a two-rating method of evaluating impact isolation," in *Proc. ICA2016*, Buenos Aires, Argentina, Sep. 2016.

[16] J. LoVerde and W. Dong, "Developing classifications using a dual-rating method of evaluating impact noise," in *Proc INTER-NOISE 2018*, Chicago, IL, 2018.

[17] J. Lo Verde, S. Rawlings, and W. Dong, "Applications for new high-frequency impact ratings," *J. Acoust. Soc. Am.*, vol. 148, no. 4_Supplement, p. 2751, Oct. 2020, doi: 10.1121/1.5147648.

[18] J. LoVerde and W. Dong, "Laboratory measurement of low-frequency impact sound," in *Proc ICSV25*, Hiroshima, 2018.

[19] W. Dong and J. LoVerde, "Quantitative comparisons of resilient channel designs in walls and ceilings," in *Proc Noise-Con 2022*, Lexington, KY, 2022.