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New ASTM ratings for high-frequency impact noise insulation

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ABSTRACT

The authors have proposed a two-rating method of evaluating impact noise isolation [1], in which low and high-frequency components are evaluated independently. The high-frequency rating is based on the existing IIC/ $L_{n,w}$ ratings, except with a limited frequency range encompassing the 400-3150 third-octave bands. The proposed ratings evaluate high-frequency impact sources and mitigation measures better than the existing ratings. These high-frequency ratings, called High-frequency Impact Rating or HIR for field testing and High-frequency Impact Insulation Class or HIIC for laboratory testing, have recently been published as a new ASTM standard. Motivations, development, and examples illustrating the use of the new ratings are presented, and suggested classification schemes are discussed.

1. INTRODUCTION

Most current classifications for impact noise insulation in multifamily housing is 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 in third-octave bands from 100–3150 Hz. There is broad agreement that frequencies below 100 Hz are important for evaluating human reaction [4], but the existing IIC or $L_{n,w}$ rating is often assumed to be suitable to evaluate the remaining frequencies.

The authors have proposed that impact noise occurs independently in two frequency domains [1]. Based on test data and supported by theoretical expectations, a separate high-frequency impact rating is the best way to design for high-frequency impact noise sources and evaluate floor coverings. This is because a broadband rating that extends down to 100 Hz (or lower) will be controlled by frequency bands that do not correlate with the high-frequency performance of the assembly.

The concept has gained some acceptance in North America. Recently, the proposed high-frequency impact ratings have been adopted as ASTM standard E3222 [7]. Here, we present the new rating with examples and suggested classifications.

2. HIGH-FREQUENCY IMPACT RATINGS

The high-frequency rating is by intent 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 (see Table 1) 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.

Band center frequency, Hz	Reference contour value, dB
400	1
500	0
630	-1
800	-2
1000	-3
1250	-6
1600	-9
2000	-12
2500	-15
3150	-18

Table 1. Reference contour for the high-frequency impact ratings.

Note that the high-frequency ratings can be easily calculated from existing test data. The ratings can therefore be calculated for previously tested assemblies and can utilize the large amount of impact test data that has been gathered over the decades.

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 2.

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	AIRC $L'_{n,w}$
HIIC	High-frequency impact insulation class	Lab $A_0 = 10$ m ²	IIC $L_{n,w}$
Δ HIIC	Improvement in HIIC	Lab $A_0 = 10$ m ²	Δ IIC ΔL_w

Table 2: New family of high-frequency impact ratings per ASTM E3222, showing normalization and correspondence with existing ratings

3. RATIONALE

For readers who are unfamiliar, we briefly review the reasoning behind the choice of frequency range for the new ratings.

The need for the new ratings is summarized by **Figure 1**. This shows the impact spectra of three typical floor-ceiling assemblies using construction systems and products common in the North American market. These floors have the same IIC/L_{n,w} rating, but vary by up to 40 dB in high-frequency impact insulation. It is sometimes assumed that new ratings or spectrum adaptation terms are required for low-frequency impact noise, but that the existing ratings can be used to evaluate high-frequency performance. This figure clearly demonstrates that this is not the case. Regardless of what ratings are used to measure low-frequency impact insulation, new ratings are required to measure high-frequency impact insulation.

The spectra in **Figure 1** are not an unusual or special case. As demonstrated in the follow sections, these spectra are not only typical of tested floor assemblies but are expected on theoretical grounds.

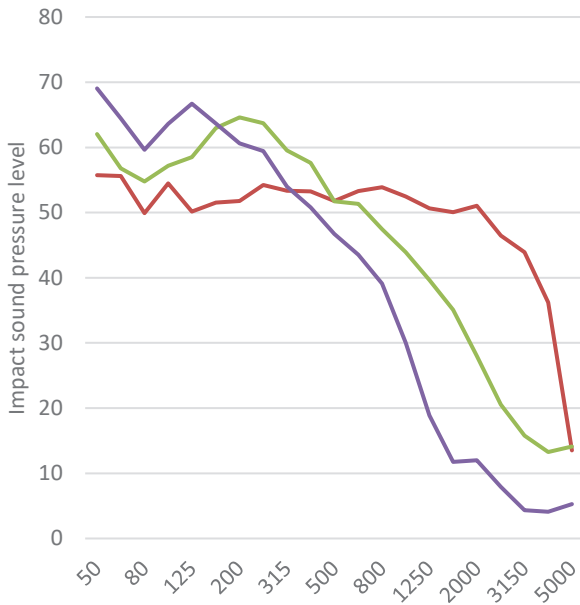


Figure 1: Example impact sound spectra for three floor-ceiling assemblies. All three curves have the same IIC/L_{n,w} rating but differ drastically in high-frequency impact insulation.

3.1 Empirical Results

As described in Ref. [1], we compiled test data from over 100 concrete buildings where impact testing was performed on both bare slab and with floor coverings, sampling a large variety of finish floor materials and resilient matting. The reduction in impact sound level due to the floor covering is shown in Figure 2. For these products, which are representative of most flooring and resilient matting products on the market in North America, a lower frequency bound of 400 Hz would adequately describe the performance of these

floors. Note that the rating is not sensitive to the exact band used as the lower frequency limit of the rating. What is important is that the lowest bands in the IIC/L_{n,w} reference curve are not included in the calculation, as *these bands often control the rating but are irrelevant to the performance of the flooring*.

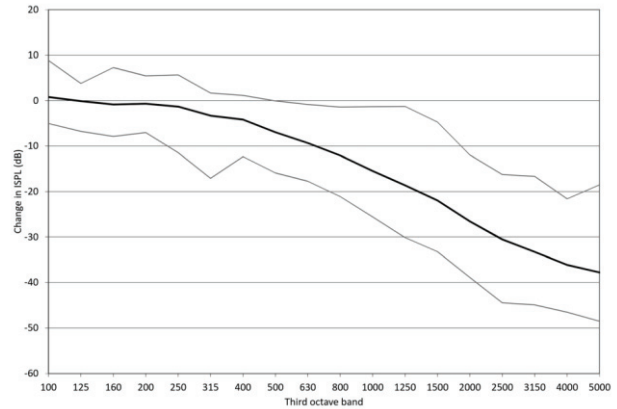


Figure 2: Average (thick line), 5th and 95th percentile reduction in impact sound relative to bare slab for 102 variations of finish floor and resilient matting. Same as Fig. 6 in Ref. [1].

3.2 Theoretical Considerations

Impact noise has long been modeled by a simple impedance model [8], [9]. The low-frequency behavior is defined 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. The high-frequency response is determined by the local compliance of the floor at the hammer location. As Waters emphasizes, resilient floor coverings do not, strictly speaking, isolate the system from forces, but reduce the generation of high-frequency vibration [9].

Following this model, 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,

$$\Delta L_n = K \lg \frac{f}{f_0} \quad (1)$$

where ΔL_n is the reduction in impact sound level at frequency f , and f_0 is the resonance frequency of the floor covering. Below f_0 , ΔL_n is negligible. The constant K (i.e., the slope of the line) depends on the details of the product and how it couples with the subfloor but is typically taken to be 30 or 40 (that is, 9 or 12 dB/octave) [10], [11]. The field testing results (Figure 2) confirm that this simple equation is a good description of the behavior of most common floor coverings.

The derivation of this behavior and the field testing mentioned above are both for a massive homogenous structure such as a concrete slab. However, we have shown that lightweight joist-framed structures show the same behavior [12], and that Eqn. (1) can describe the improvement in impact insulation due to floor coverings for all structural systems.

Assuming the Eqn. (1) is correct with $K = 40$, and knowing the impact sound level of a structural system without a floor covering (measured in a laboratory), we can calculate the single number ratings for the assembly with a theoretical floor coverings of arbitrary resonance frequency. The resultant single number ratings are shown in Figure 3 for 200 mm concrete slab, and in Figure 4 for 457 mm open web wood trusses.

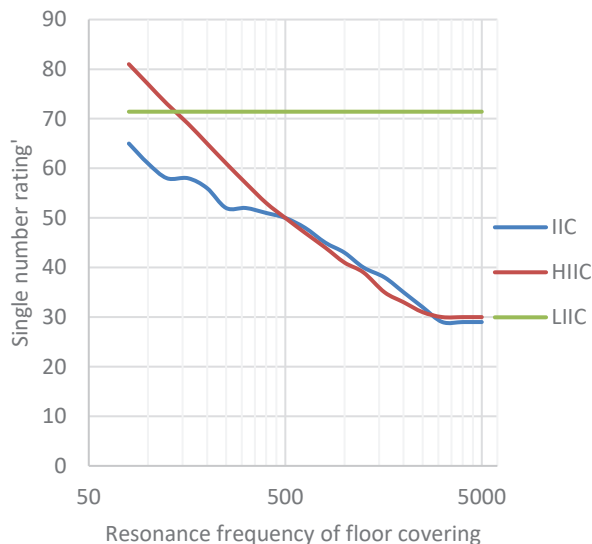


Figure 3: Single number ratings as a function of resonance frequency of the theoretical floor covering for 200 mm concrete slab

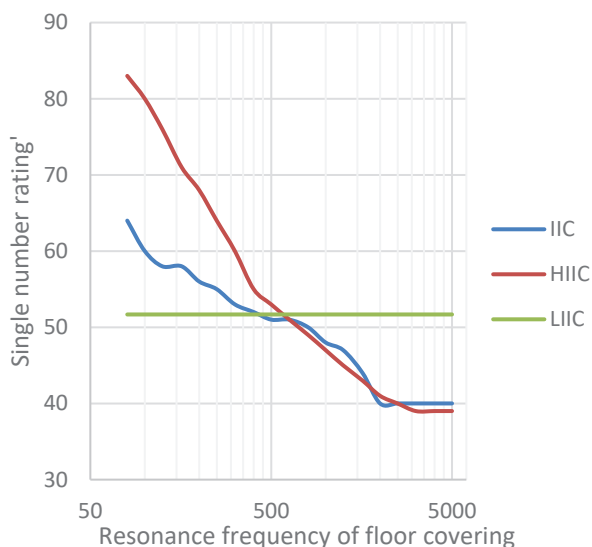


Figure 4: Single number ratings as a function of resonance frequency of the theoretical floor covering for 457 mm open web wood trusses

The LIIC rating (Low-frequency Impact Insulation Class) is also shown in these figures. This rating evaluates impact sound below 100 Hz. We do not discuss it further except to note that low-frequency impact sound is not affected by floor covering and is therefore constant in the figure.

The shapes and values of these curves will depend upon the spectra of the bare assembly, but the trends

are the same for different structural systems. A very high resonance frequency indicates a hard floor covering with surface resilience similar to the bare structure. Therefore, the floor covering has no effect, and the ratings are the same as for the bare slab (the far right hand side of the curves are constant). Both IIC and HIIC ratings indicate steadily improving isolation as the resonance frequency of the floor covering decreases, but at some point the IIC (and equivalently, $L_{n,w}$) curves flatten. This is an illustration of the issue described above that led to the development of HIIC. As can be seen, the limited frequency range of the HIIC rating allows it to continue to accurately describe the improvement of floor coverings with low resonance frequencies.

For lower-rated floors, there is no significant difference between the existing and high-frequency ratings (e.g., IIC and HIIC). This is because those floors tend to be controlled by deficiencies at high frequencies. As the floors improve (i.e., the resonance frequency of the floor covering decreases), the existing ratings such as IIC become more and more influenced by the sound level below 400 Hz, which is why the spectra in **Figure 1** have the same IIC rating. The high-frequency rating continues to increase as the flooring improves; there is a 16-point improvement in HIIC rating from the red to the purple spectra in **Figure 1**. Therefore, the existing ratings do not adequately represent the behavior of the assemblies at high frequencies.

4. SUBJECTIVE EVALUATION

4.1 High-frequency Impact Sources

Common high-frequency impact sources in residences include heel clicks from footfall with hard-soled shoes, dropping objects, dragging furniture, and dog toenails. While much attention has been paid to low-frequency “thudding” from footfalls, high-frequency impact sources also cause complaints in multifamily projects.

There is much evidence that occupants are sensitive to high-frequency impact noise even with significant low-frequency footfall noise. We have previously reported on an iterative optimization program of the floor-ceiling assembly for a large developer of high-rent multifamily homes [13]. The resulting assembly has mediocre low-frequency isolation but good performance at high frequencies, and the isolation is considered good by most tenants.

We have also reported [14] on recent field testing experience in a number of projects where mitigation was successfully implemented (as judged by occupant complaints) that significantly increased the high-frequency rating while the broadband rating remained unchanged. The high frequency rating predicted the subjective reaction, while the broadband rating did not correlate with either the measured spectra or the subjective reaction.

While there is no doubt that low-frequency footfall noise causes complaints, isolation against high-frequency sources is also important to occupant

reaction. Further, the existing ratings do not adequately represent the level of high-frequency performance of an assembly or floor covering.

4.2 Classification

We preliminarily suggested the classification system shown in Table 3 [14]. The classification is in terms of NHIR, which is the high-frequency impact isolation normalized to a reverberation time of 0.5 second. The classes A–D are intended to correspond to the performance of the classifications of Ref. [4] and ISO Draft Technical Specification 19488 [15]. These classifications are suggested as a starting point for discussion and have not been adopted by any regulatory agency.

	NHIR
Class A	65
Class B	58
Class C	52
Class D	45

Table 3: Suggested classification for high-frequency field ratings.

5. IMPLEMENTATION

5.1 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 (c.f. Figure 3 and Figure 4). 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 Δ HIIC ratings instead of IIC and Δ IIC will greatly clarify the situation. Products can be accurately rank-ordered and cost-benefit decisions can be made more accurate. Several manufacturers have already started calculating and publishing the high-frequency ratings for their tested assemblies.

5.2 Flooring Changes

One class of projects where the high-frequency ratings are particularly useful is buildings where the finish flooring is regularly altered (e.g., condominiums, hotels, schools) and the performance of the flooring needs to be evaluated and regulated. Many condominiums are older wood joist buildings with poor performance at low frequencies, but still wish to require flooring products that achieve a level of performance regarding high-frequency sources.

For many buildings, it is impossible to achieve this goal using the existing ratings. As an example, in one building discussed in Ref. [1], the floors with resilient matting were clearly preferred to floors without. This is obvious from examination of the impact spectra (Figure 5), but the ISR ratings of these spectra are almost identical. 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.

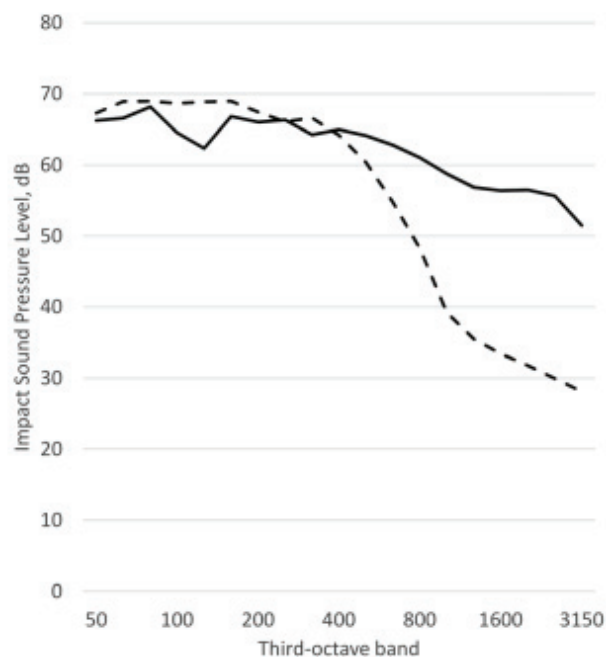


Figure 5: Impact spectra from the building discussed in the text. Same as Fig. 8a from Ref. [1]

Now that the high-frequency ratings have been published as an ASTM standard, we encourage and expect regulatory bodies such as condominium associations to adopt the high-frequency ratings instead of the existing ratings to evaluate and regulate permissible flooring.

6. CONCLUSION

The traditional broadband impact ratings ($IIC/L_{n,w}$) are a poor choice for representing the performance of assemblies at high frequencies. They do not accurately evaluate assemblies, either in terms of the physical behavior or subjective reaction. To address this, a new high-frequency impact rating method has been developed with a frequency range that is limited to the range of interest. This new family of high-frequency impact ratings, each corresponding to an existing rating, has been defined and recently published as ASTM E3222. The new ratings do not require any change in measurement procedure.

The new ratings can be used to evaluate the performance of assemblies from high-frequency impact sources. Use of the new ratings in flooring specifications and requirements will improve the comparison and rank-ordering of products and systems, and provide additional information to designers of floor-ceiling systems.

7. ACKNOWLEDGEMENTS

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