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DEVELOPMENT OF A RATING FOR EVALUATING THE IMPROVEMENT IN HIGH-FREQUENCY IMPACT ISOLATION

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The authors have introduced a new impact noise isolation metric for high-frequency sources named High-frequency Impact Rating (HIR), which encompasses the frequency range of 400-3150 Hz. The advantages of this rating include better correlation with subjective reaction and improved rank-ordering of finish flooring and sound mats. A natural extension of this metric is to define a rating of the improvement in impact isolation analogous to ΔIIC per ASTM E2179 and ΔL_w per ISO 717-2. The resulting metric ΔHIIC evaluates the improvement in high-frequency impact isolation due to floor coverings as measured in the laboratory. Application of the metric to design and evaluation of floor-ceiling assemblies is presented.
Keywords: high-frequency, impact isolation, footfall, HIR

1. Introduction

The impact isolation of a floor-ceiling assembly is of the entire assembly, not of just the floor covering. (Here floor covering refers to the materials installed on the upper surface of the subfloor or base assembly, which in addition to the finish floor may include sound mats, slip sheets, adhesives, etc.) However, it is often desired to characterize the performance of a floor covering system or product independently of the base assembly. To this end, ASTM E2179 [1] defines ΔIIC as the "improvement in impact insulation class" by floor coverings while ISO 717-2 [2] similarly defines ΔL_w as the "reduction in impact sound pressure level" due to floor coverings. These ratings are intended to provide an indication of the rating that would be achieved by the floor covering if installed on a typical monolithic, heavyweight concrete slab.

The authors have recently published a new dual-rating system for evaluating impact noise isolation, in which the noise level in the low frequency and high frequency bands are evaluated independently [3]. In this paper we focus on the high-frequency component of impact noise, typically due to impact on hard-surfaced finish floors by sources such as hard-soled shoes during footfall, dragging furniture legs, and dropping objects. We here explicitly define a family of high-frequency ratings, including improvement of impact insulation, and show that they result in consistently improved ability to evaluate and assess acoustical performance of high-frequency impact sources.

2. Impact ratings

2.1 Existing ratings

The impact sound pressure level (ISPL) of any assembly is measured using the standard tapping machine as the impact source. The measurement procedures are defined in ASTM E492 [4] and ISO 10140-3 [5] for the laboratory, and ASTM E1007 [6] and ISO 16283-2 [7] for the field. While there are some differences in details, the measurement methods are similar between the ASTM and ISO methods.

The corresponding ratings are defined in ASTM E989 [8] and ISO 717-2 [2]. Both ASTM and ISO classifications use the same reference curve spanning the same frequency range, and the same curve fitting method. The only difference in the classifications is that the ASTM method includes the “8 dB rule” which is a second criterion that limits the maximum allowed deficiencies in any band to 8, in addition to the 32 total deficiencies allowed in both standards.

In the remainder of this paper we refer to the ASTM ratings; however, the results are easily extended the ISO ratings if desired.

The shortcomings of the existing single number ratings (IIC/$L_{n,w}$) with regards to low-frequency “thudding”, particularly in lightweight structures, have received considerable study. Such thudding typically occurs below the 100 Hz lower limit of the IIC/$L_{n,w}$ ratings. Several methods to quantify this low-frequency noise have been developed, including the spectrum adaptation term $C_{I,50\text{-}2500}$ [2] and the authors’ proposed Low-frequency Impact Rating (LIR) [3] (both of which use the standard tapping machine), as well as the use of the heavy/soft impact source [7].

In heavyweight buildings with poured concrete structure, the low-frequency (thudding) component is typically less important. In these buildings, impact noise is primarily in the mid- and high-frequency portion of the spectrum, and typically due to impact on hard-surfaced finish floors by sources such as hard-soled shoes during footfall, dragging furniture legs, dog toenails, and dropping objects. It is often assumed that the IIC/$L_{n,w}$ ratings perform reasonably well for such assemblies. However, we have shown [3] that the existing ratings experience the opposite problem: they include frequencies that control the rating but are irrelevant to the design. Specifically, when using the standard tapping machine as the source, changes due to floor covering typically occurs only in the frequency range above 400 Hz.

2.2 High-frequency impact ratings

The authors compiled 102 field impact tests where testing was performed both before and after installation of a resilient flooring or acoustical resilient matting product. All were poured concrete slabs from 150–200 mm in thickness, with a variety of ceilings conditions. The resilient acoustical mats ranged from 1 mm to 17 mm in thickness consisting of a variety of common materials. Figure 1 shows the change in ISPL with frequency, along with the 5th and 95th percentile limits. (This is Figure 6 from Ref. 3.) The average change in ISPL is near zero at low frequencies up to 400 Hz, and increases rapidly above 400 Hz. For any given floor covering, there is no change or a small amount of amplification (1-2 dB) relative to the bare concrete floor at lower frequencies, followed by a well-defined “knee” and a rapid decrease in ISPL with increasing frequency. With a few exceptions, the frequency range of interest for such products begins at 400 Hz. This behavior is common to all assemblies, which allows for a generalized assessment and evaluation using a method that takes this behavior into account.

Not only are the changes limited to ISPL above 400 Hz, but for a wide range of assemblies, the overall IIC/$L_{n,w}$ ratings are controlled by the ISPL below 400 Hz. Because the ISPL at these frequencies does not typically change with changes in floor covering, the existing ratings are therefore *not* representative of the effectiveness of the assembly with respect to mid-and high-frequency impact noise. The authors therefore proposed a new rating called High-frequency Impact Rating (HIR) to evaluate the performance at these frequencies. The reference spectrum is the same as the existing reference spectrum except that the lowest frequency band is 400 Hz. The curve fitting procedure is the same as IIC, with a maximum of 20 deficiencies (2 per band). Following the ISO standard, the 8 dB rule is not implemented.

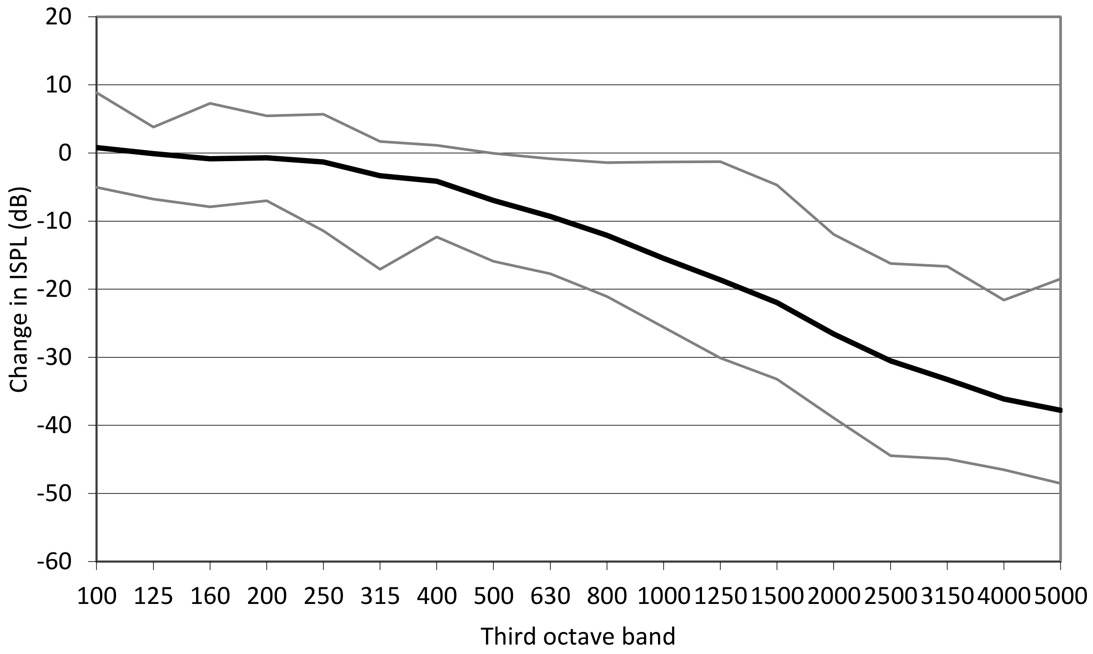

Figure 1: Change in ISPL for heavyweight concrete slabs with the additional of resilient floor covering. The dark line is the average and light lines are the 5th and 95th percentile.

The proposed rating does not change the method by which the ISPL in each third-octave band is determined. It is only a new classification, i.e., the method for determining a rating, and can therefore be applied to any third-octave ISPL. HIR is defined using non-normalized ISPL. Following the naming convention of existing ASTM ratings, we define Normalized HIR (NHIR) using ISPL normalized to a standard reverberation time of 0.5 seconds (RTNISPL in E1007 [6]), and Absorption-normalized HIR (AHIR) using ISPL normalized to a 10 m^2 of absorption in the receiving room (ANISPL in E1007 [6]). The laboratory rating is High-frequency Impact Insulation Class (HIIC).

The improvement in HIIC (ΔHIIC) can also be measured in the same manner as ΔIIC or ΔL_w. The ISPL is measured both on the bare concrete slab and with the covering installed on the slab. The difference in each band is then subtracted from a reference spectrum (to account for differences between bare slabs). The ΔHIIC is the difference between the ratings of the difference and reference spectra (the reference spectrum has an IIC of 28 and an HIIC of 29).

Note that this rating can be easily calculated from existing test data, and can therefore be evaluated for previously tested assemblies.

The ratings are summarized in Table 1, and the correspondence between the new high-frequency metrics and the existing ASTM and ISO metrics is shown in Table 2.

Table 1: Proposed family of high-frequency impact noise single-number ratings.

	Rating	Name	Normalization
Field tests	HIR	High-frequency Impact Rating	None
	NHIR	Normalized HIR	$T_0 = 0.5$ s
	AHIR	Absorption-normalized HIR	$A_0 = 10$ m^2
Laboratory tests	HIIC	High-frequency Impact Insulation Class	$A_0 = 10$ m^2
	ΔHIIC	Improvement in HIIC	$A_0 = 10$ m^2

Table 2: Correspondence between proposed high-frequency ratings and existing single-number ratings.

	High-frequency	Existing	
Frequency Range	400-3150 Hz	100-3150 Hz	
		ASTM	ISO
Field tests	HIR	ISR	L'_w
	NHIR	NISR	$L'_{nT,w}$
	AHIR	AIIC	$L'_{n,w}$
Laboratory tests	HIIC	IIC	$L_{n,w}$
	ΔHIIC	ΔIIC	ΔL_w

3. Improvement in Impact Insulation Testing

3.1 Results and Analysis

The authors recently assisted in a series of laboratory tests of the improvement of impact noise insulation with a variety of finish flooring products. The products were luxury vinyl tile (LVT) finish flooring in various thicknesses both with and without sound mat, which were foam pads. The products were tested on both nominal 150 mm (6 inch) and 200 mm (8 inch) concrete slabs without a ceiling. (E2179 [1] defines the thickness of the standard specimen as 150 ± 50 mm, with 150 mm preferred.) The results are shown in Tables 3 and 4, including both existing and new ratings. The ISPL spectra for the tests on the 200 mm slab are shown in Figure 2.

Table 3: Results of testing program on 150 mm slab.

Covering	IIC	HIIC	ΔIIC	ΔHIIC
None (average)	27	27	--	--
2mm LVT	33	32	6	5
5.5mm LVT	48	48	21	20
2mm LVT with sound mat	52	55	23	27
5mm LVT with sound mat	53	60	24	31
5.5mm LVT with sound mat	55	62	25	33
Carpet Tile 1	66	88	30	60
Carpet Tile 2	57	64	28	36
Carpet with pad	85	91	49	63

Table 4: Results of testing program on 200 mm slab.

Covering	IIC	HIIC	ΔIIC	ΔHIIC
None (average)	29	30	--	--
2mm LVT	34	34	5	4
5.5mm LVT	46	44	16	14
2mm LVT with sound mat	56	59	23	26
5mm LVT with sound mat	58	65	24	32
5.5mm LVT with sound mat	55	63	23	30
Carpet Tile 1	67	89	31	56
Carpet Tile 2	61	70	28	37
Carpet with pad	88	94	47	62

Tables 3 and 4 demonstrate typical behaviour of the existing ratings. For assemblies with poor isolation, the IIC and HIIC are similar, because these assemblies are controlled by the ISPL above 400 Hz. As the assembly improves, the ISPL at high frequencies drops while the ISPL at the lower frequencies is essentially unchanged. This behaviour is clearly seen in Figure 2. At some point, the IIC rating becomes controlled by the ISPL below 400 Hz, and the rating stops increasing with further improvement at higher frequencies. In Tables 3 and 4, the IIC rating for hard-surfaced flooring is limited to a maximum value in the mid-50's.

For example, the IIC ratings for all three LVT types with sound mat are within 1-2 points of each other, which is approximately the precision of the measurement method. One therefore might conclude that they have similar performance. From Figure 2, however, the 2mm LVT is 7–10 dB louder than the others in the 500–2000 Hz range and is an inferior acoustical product for high-frequency impact sources. The IIC rating is controlled by the levels in the 125–315 Hz bands, and is unresponsive to the changes at higher frequencies. By contrast, the HIIC rating continues to increase with reduction in noise level, and the HIIC rating of the 2mm LVT is 5–7 points lower than the others, in line with the actual performance.

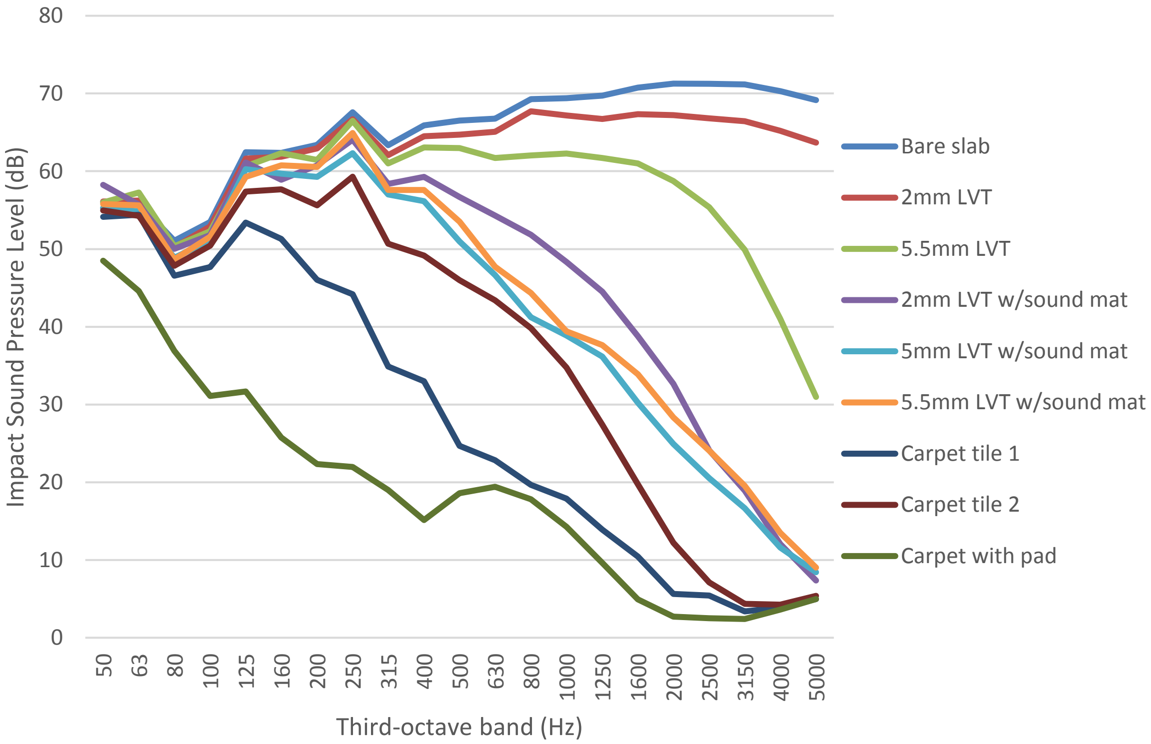

Figure 2: ISPL spectra for laboratory testing of various floor covering on 200 mm concrete slab.

Because it is based on the same rating, ΔIIC suffers from the same problem as IIC. As the performance of the floor covering is improved, the rating becomes limited by the level in the 100–315 Hz bands. For hard-surfaced flooring, the rating rarely exceeds ΔIIC 25. One of the primary benefits of the new ratings compared to the existing is evaluation and rank-ordering of floor covering. As this is the purpose of the improvement rating, restricting the frequency range to above 400 Hz will be even more beneficial for the improvement rating.

The ΔIIC ratings in Table 3 and 4 show the same behaviour as the IIC ratings, and the ΔHIIC ratings again show increased range and better correlation with the performance of the covering as seen in Figure 2. The relationship between IIC and HIIC for the hard-surfaced tests in Table 3 and 4 is graphed in Figure 3. For ratings controlled at higher frequencies, which is typical of assemblies with poor ratings, the high-frequency and existing ratings are very similar (line in Figure 3). However, for better performing floors, the ΔIIC ratings do not extend beyond the mid-20's. The ΔHIIC ratings, however, continue to improve as the covering improves. In Figure 3, the points therefore leave the line, and the spread of the points along the ΔHIIC (vertical) axis is roughly twice the spread along the ΔIIC (horizontal) axis.

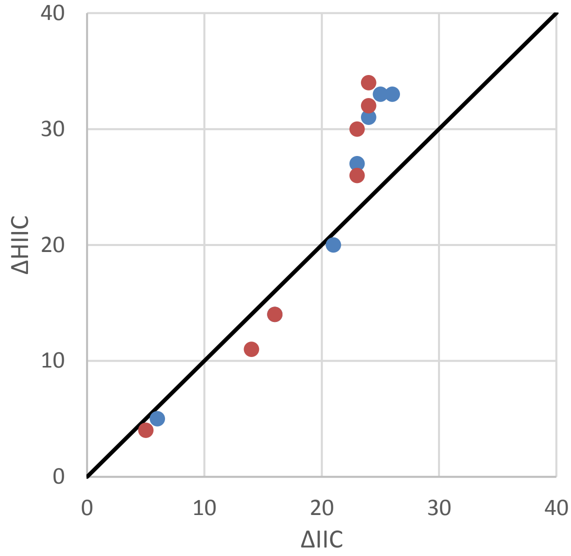

Figure 3: Comparison of HIIC (proposed high-frequency rating) versus IIC (existing rating) for the hard-surfaced tests in Tables 3 and 4. Blue points are 150 mm slab and red points are 200 mm slab. The line is the locus of points with identical ratings.

3.2 Predictive ability

Ideally, the overall rating of an assembly could be calculated from the rating of the bare floor added to the improvement rating due to the covering. With IIC, however, this process is often "contaminated" because the rating is controlled by portions of the spectrum that do not depend on the covering. Even in the controlled environment of the laboratory, simply adding the ΔIIC of the covering to the IIC of the bare slab does not reliably yield the IIC of the assembly.

We quantify the error in prediction as $IIC - (IIC_{bare} + \Delta IIC)$, and similarly for ΔHIIC. Histograms of the errors for the tests in Table 3 and 4 are shown in Figure 4. The ΔIIC rating does not perform well as a predictive method, with roughly half of the tests having errors of more than 3 points. The ΔHIIC performs much better, with all of the errors within 3 points and half of the errors within 1 point.

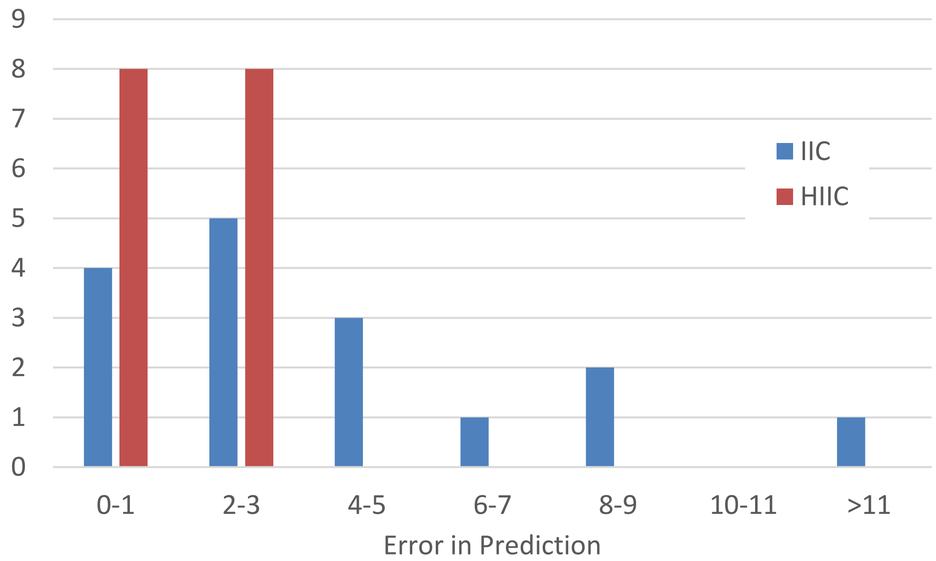

Figure 4: Histogram of the error in prediction for IIC and HIIC ratings.

4. Summary

The improvement of impact insulation due to floor covering is primarily a high-frequency problem, in the range of 400 Hz and above. The existing IIC and $L_{n,w}$ ratings are often controlled by frequency ranges that are not affected by floor covering, and therefore do not adequately correlate with the performance of the covering. Restricting the frequency range of the impact noise measurement to 400–3150 Hz, without otherwise changing the test, results in improved evaluation of covering. The authors propose ratings HIR, NHIR, and AHIR to define high-frequency impact performance in the field, and HIIC and ΔHIIC for laboratory measurements. ΔHIIC for evaluating the improvement in High-frequency Impact Insulation Class is shown to be superior to the existing ΔIIC in rank-ordering floor covering installed on concrete slab.

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