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Ratings and classifications for high-frequency impact noise isolation

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ABSTRACT

A two-rating method of evaluating impact noise isolation has been proposed by two of the authors (1), in which low and high-frequency components are evaluated independently. Numerous other researchers have investigated the issue, and although the details differ, there has been some convergence of ratings and classifications for low-frequency impact noise. For the high frequencies, most have assumed that the existing IIC/$L_{n,w}$ ratings are appropriate, while the authors have proposed high-frequency ratings which are based on the existing ratings but with a limited frequency range of 400–3150 Hz. Analysis of impact data from floor assemblies common to North America shows that the proposed ratings evaluate high-frequency impact sources and mitigation measures better than the existing ratings. The analysis is extended to include data from German floor systems and heavyweight and lightweight stairs. The ratings are compared and possible classifications are suggested.

Keywords: High-frequency, Impact, Insulation,

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 both based on the impact noise level in third-octave bands from 100–3150 Hz. There is agreement by other researchers 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. Other researchers are attempting to create new reference curves that include both low and high frequencies (5,6).

Two of us have proposed that impact noise occurs independently in two frequency domains (1). While we arrived at this conclusion empirically based on our experience in field testing, theoretical models of impact noise lead to the same conclusion that a separate high-frequency impact rating is the best way to design for high-frequency impact noise sources and evaluate floor coverings.

The work has to date been based on test data collected in North America and therefore based on assembly types that are common there. Other countries have different construction methods and traditions. Here we extend the analysis to examine some common German floor-ceiling assemblies.

2. HIGH-FREQUENCY IMPACT NOISE

2.1 Theoretical Behavior of Floor Coverings

Impact noise has long been modeled by a simple impedance model (7,8). 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

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response is determined by the local compliance of the floor at the hammer location. As Watters emphasizes, resilient floor coverings do not, strictly speaking, isolate the system from forces, but reduce the generation of high-frequency vibration (8).

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,

$$\Delta L_n = K \lg \frac{f}{f_0} \tag{1}$$

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. Vér derives a value of 40 for locally reacting resilient flooring and 30 for point-supported floors (9). ISO 12354-2 (10) Annex C recommends 30 for floating floors with screeds of sand/cement or calcium-sulphate and 40 for asphalt or dry floating floors.

These derivations generally assume that the floor coverings are installed on a rigid, heavy structure such as a poured concrete slab, that is, where the mobility of the structure is much lower than the mobility of the floor covering. How does the theory extend to lightweight floors that are framed with wood or light gauge steel joists? Unlike monolithic slabs, no analytical solutions are available; one technique is to develop numerical models (11). For our purposes, we do not need to be able to calculate the mobility of the joist-framed structure; we can empirically determine if a similar behavior applies.

In Figure 1 we compare the improvement in impact insulation provided by three common floor coverings on a 200 mm (8 in.) concrete slab and two lightweight wood-framed assemblies, one framed with 457 mm (18 in.) open-web wood trussed and one with 300 mm (12 in.) wood I-joists. Both have a thin (about 19 mm) gypsum concrete pour and a gypsum board ceiling attached with resilient channel. Note that the fall-off at high frequencies is due to the noise floor in the laboratory. The curves are not identical, and the performance is in general better with the heavyweight floor as opposed to the wood joist floors. However, we can conclude that the structural properties do not change the essential behavior of floor coverings, and that Eq. (1) is approximately correct for all structural types.

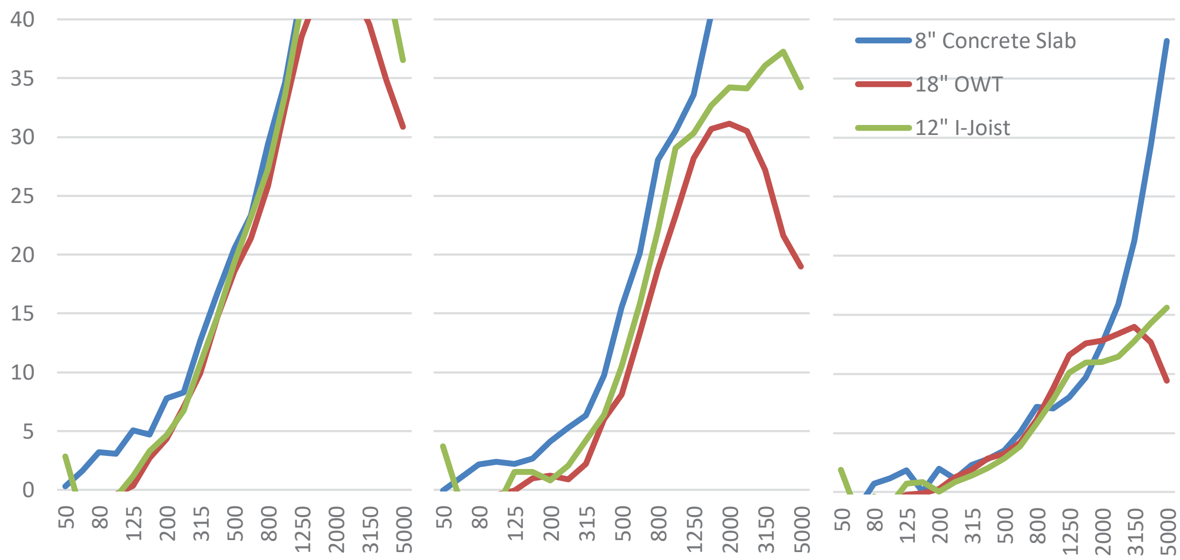

Figure 1–Improvement in impact insulation (reduction in impact sound level) on three structural systems for carpet tile (left), luxury vinyl plank over foam mat (middle), luxury vinyl plank without sound mat (right).

2.2 Proposed single number ratings

The authors have demonstrated (1) that changes in impact sound level due to floor covering can be described by considering only the third-octave bands from 400 Hz and above. Although floor coverings with resonance frequencies below 400 Hz are readily available, due to the shape of the rating curve, the IIC ratings for assemblies with such floor coverings are controlled by the bands below 400 Hz. Therefore, while lower resonance frequencies results in better IIC or $L_{n,w}$ ratings in general, this relationship breaks down for floor coverings with low resonance frequencies, and the rating tends to stop changing even as the resonance frequency continues to decrease. That is, the IIC/$L_{n,w}$ ratings are not representative of the effectiveness of the floor covering.

The authors therefore proposed a family of new high-frequency ratings to better evaluate the acoustical performance of floor coverings and high-frequency noise sources in general (Table 1). The laboratory version is called High-frequency Impact Insulation Class (HIIC). The reference spectrum and calculation method is the same as the existing ratings except that the lowest frequency band is 400 Hz. The maximum deficiencies remain at 2 per band (20 total); the 8 dB rule is not implemented. Note that this rating can be easily calculated from existing test data, and can therefore be evaluated for previously tested assemblies.

Table 1– Proposed family of high-frequency impact noise single-number ratings and their correspondence with existing ratings.

	Rating	Name	Normalization	Existing Ratings	
				ASTM	ISO
Field	HIR	High-frequency Impact Rating	None	ISR	L'_{w}
	NHIR	Normalized HIR	T_0 = 0.5 s	NISR	$L'_{nT,w}$
	AHIR	Absorption-normalized HIR	A_0 = 10 m^2	AIIC	$L'_{n,w}$
Lab	HIIC	High-frequency Impact Insulation Class	A_0 = 10 m^2	IIC	$L_{n,w}$
	ΔHIIC	Improvement in HIIC	A_0 = 10 m^2	ΔIIC	ΔL_w

2.3 Behavior of Single Number Ratings

Here we proceed with the assumption that Eq. (1) is accurate. 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. Figure 2 shows the IIC and HIIC rating of a floor as a function of floor covering resonance frequency for the same three structural systems referenced above.

The LIIC rating (Low-frequency Impact Insulation Class) is also shown. This rating evaluates impact sound below 100 Hz; higher ratings are better. 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.

A very high resonance frequency indicates a 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.

It is apparent from Figure 2 that the "branching point" between the IIC and HIIC depends on the structural assembly. The existing IIC rating performs worse with the lightweight assemblies, while with the concrete slab, the branching point is at a lower frequency and there is a smaller difference between the ratings.

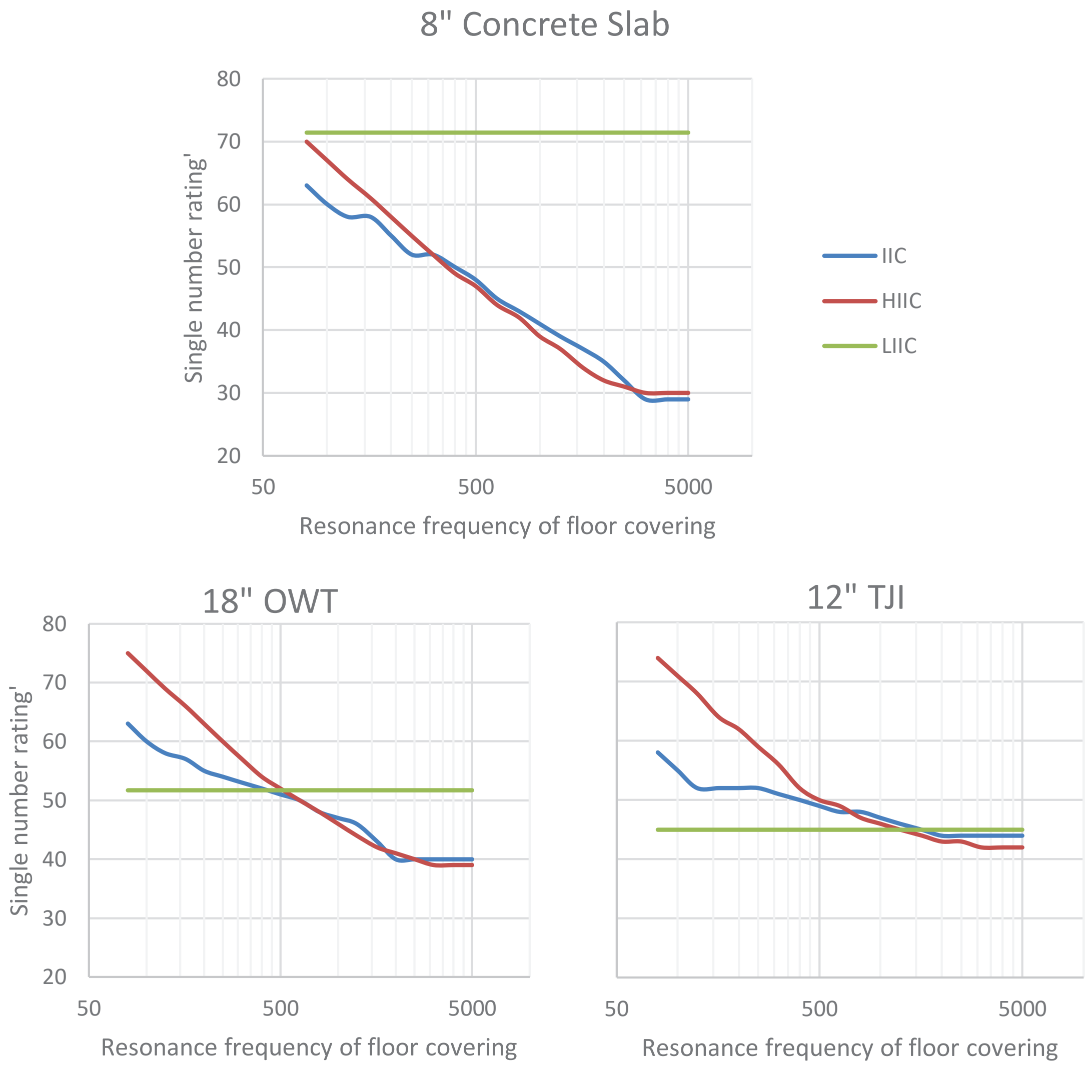

Figure 2 – Single number ratings as a function of resonance frequency of theoretical floor covering behaving as Eq. (1) for three structural systems: 200 mm concrete slab (top), 457 mm open web wood trusses (bottom left), and 300 mm wood I-joists (bottom right).

3. GERMAN FLOOR-CEILING ASSEMBLIES

The above analysis was based on assemblies common in North America. Typical German residential projects have concrete slab structure with an approximately 5 cm screed over various resilient mattings. The resonance frequencies of the floating floor can be as low as 50 Hz. In the shower pans, thinner resilient matting is used to accommodate the waterproofing and drainage systems. There are also lateral impact issues with both concrete and wood or steel stairs mounted to the separating wall between units. Single number ratings for these assemblies is shown in Table 2 and the spectra are graphed in Figure 3.

Table 2– Single number ratings for some common German floor assemblies.

Condition	$L_{n,w}$	IIC	HIIC
Typical living space	44	62	73
Shower system 1	49	56	71
Shower system 2	39	71	72
Lightweight stair	40	66	81
Heavyweight stair, isolated	38	72	70
Heavyweight stair, unisolated	69	38	39

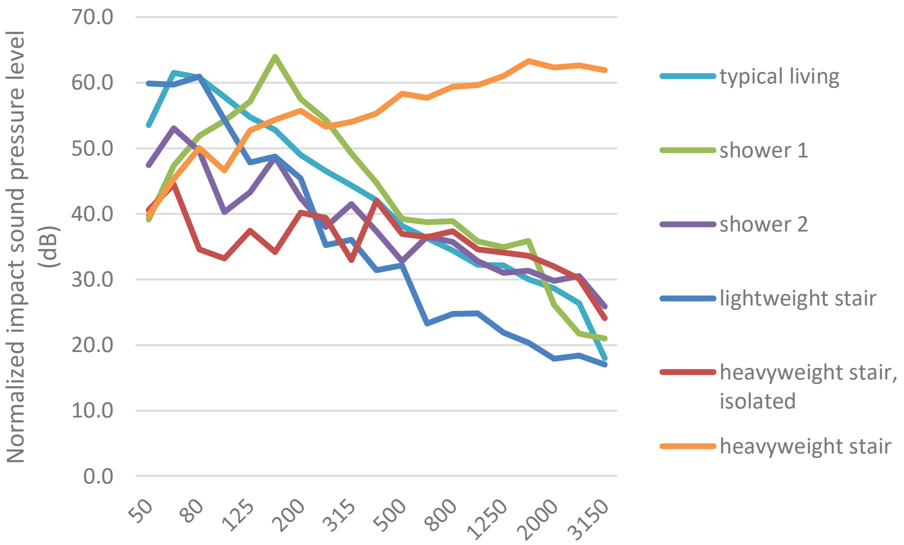

Figure 3 – Impact spectra of the German floor-ceiling assemblies shown in Table 2.

Although these assemblies have wildly different levels at the lower frequencies, they are consistent in the high-frequency side of the spectrum. Except for the stairs, the HIIC ratings are within a few points of each other. In addition, the high-frequency performance is very good. The authors had previously suggested (13) that an HIIC rating of 65 would be considered Preferred or Class A in the North American market; all of these floors exceed this rating (excluding the un-isolated concrete stair).

For these assembly types, the high-frequency isolation is good enough (meets a Preferred standard) that only the low-frequency issue remains to be solved; in practice, the problem is reduced to a single dimension. The exception is the un-isolated concrete stair, which has, as expected, poor high-frequency performance. Thin resilient mats are placed below the finish flooring on top of the un-isolated concrete stair may be a situation one might observe the benefits of the high-frequency ratings as seen in North American assemblies. This condition is relatively uncommon. Additionally, Figure 2 suggests that the benefit of using HIIC instead of IIC is smaller for concrete slab structures compared to lightweight assemblies.

Considering these factors, therefore, it may not be surprising that researchers used to these types of assemblies do not experience the same motivation to improve the evaluation of high frequency impact noise as researchers in North America. However, this does not mean that the high frequency ratings should not be analyzed or reviewed, if only to ensure that the situation reduces to a single frequency domain. As described previously, there are strong theoretical reasons to consider impact isolation in two frequency domains. Design practices can change, and high frequency insulation may become more important in the future.

4. CONCLUSIONS

The theoretical behavior of floor coverings is well documented in both theory and experiment, that the benefit increases directly with the reduction in the resonance frequency of the floor covering. As the resonance frequency is lowered, IIC and HIIC are initially similar, but at some resonance frequency the IIC ratings levels off while HIIC continues to accurately track the floor covering. The frequency at which the ratings diverge and the magnitude of the difference between IIC and HIIC depends on the structural system.

Analytical expressions exist for the improvement due to floor coverings for monolithic slabs; while lightweight assemblies are more difficult to analyze, experiments indicate that the performance of floor coverings is approximately the same on lightweight assemblies as on heavyweight ones. The benefit of HIIC over IIC is greatest on lightweight systems.

In the North American market, lightweight separating floor-ceiling assemblies are common, and the benefit of HIIC over IIC is clear. In German residences, the standard assemblies already have very good high frequency impact insulation due to the topside isolation common to the construction of these assemblies. In this condition where one frequency domain is already at the preferred state, the problem is reduced to a single dimension. This may reduce the motivation for improving the high frequency insulation metric in these markets, but it should not be ignored. Both frequency domains are present and should be evaluated, even if it turns out that only one will be significant, as construction methods change and that may not always be the case. A dual-rating method is suggested to better evaluate impact noise insulation over all types of building construction.

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