PREDICTING FIELD IMPACT ISOLATION BASED ON THE RATING FOR IMPROVEMENT IN HIGH-FREQUENCY IMPACT ISOLATION

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Abstract
A common acoustical design task is to predict the impact rating that will obtain when an existing floor system is modified by adding or changing flooring elements. This work arises often in condominium units, when owners change finish flooring but need to maintain the level of impact isolation, and in adaptive reuse projects, in which existing commercial or industrial buildings are converted to residential use. Some previous prediction attempts have included measurement of mock-up partial flooring installations, but this has not proven satisfactory. Laboratory measurement of the improvement in impact insulation potentially offers a better method. The improvement methods are currently defined in ASTM standards only for concrete assemblies. Here we investigate the improvement in impact insulation due to floor toppings with various wood-framed assemblies to develop an appropriate reference specimen. Experience and theoretical analysis indicate that the improvement is limited to the frequency range above 400 Hz. Therefore, the authors recently introduced the ΔHIIC rating [“Development of a Rating for Evaluating the Improvement in High-frequency Impact Isolation,” in Proc. ICSV 24, London, England, UK, 2017], an improvement rating limited to high frequencies, which may result in more reliable predictions of future impact isolation.

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1. Introduction

Predicting impact noise isolation is a common design task for an acoustical professional. When designing new construction, the prediction is based on theory, laboratory test data, and experience. However, design in existing buildings allows for more empirical methods. In buildings within the USA, owners are allowed to replace flooring so long as a minimum impact ratings as defined within the Building Code. When the building is a condominium, owners are often asked to meet a requirement that is higher than the Building Code. Those replacing flooring wish to be certain of a positive outcome before spending the high cost of installing new flooring. Similarly, adaptive reuse projects place residential units in existing non-residential buildings. In these situations, it is possible to measure the impact isolation of the existing base structure, which should allow for more precise predictions of the impact ratings when the flooring (including various sound mats and acoustical materials) are installed.

One method that has been used rather universally is to test a mockup sample, in which a small area of the floor is tested. Unfortunately, our experience indicates that this method is not reliable [1]. Another method is to use laboratory tests on the improvement in impact insulation, in conjunction with the test on the existing assembly. This has also proved to be less than satisfactory, and considerable work remains to improve this method.

2. Mockup testing

In the condition where the floor structure exists and the only change will be the addition of a floor covering (finish floor and possibly including a sound mat below the finish floor), an obvious method for predicting the future impact noise with the floor covering installed is to test a mockup of the floor installation. This is typically a section of flooring on the order of 1.5 m x 1.5 m (5 ft. x 5 ft.) installed on the existing structure. The impact insulation is measured with the tapping machine on the mockup installation.

It is common to perform such mockup testing in condominiums. When the homeowner desires to renovate the flooring, the existing flooring is removed down to the structure, which is typically bare concrete (either the structural slab for concrete structures, or the gypsum concrete topping or scrim for joist-framed structures). A mockup is installed on the bare concrete and tested. This is sometimes required by the condominium documents and sometimes for the owner's peace of mind that the final installation will meet the building standards.

Usually, the floor must also be tested after the installation of the entire floor to demonstrate compliance. This allows a comparison of the mockup test and the final test. Figure 1 shows a comparison between the Impact Sound Ratings (ISR) of the mockup and the final floor for a number of recent tests. From examination of Fig. 1, it appears that the mockup tests accurately represent the final result only on average, but with the variance being far too wide for prediction. For any individual test, the mockup and final test can vary widely, which is not acceptable. The wide scatter in the result makes mockup testing unsatisfactory as a method of prediction.

The distribution of the difference between the rating predicted from the mockup and the actual result is shown in Figure 2. The distribution is approximately normal and has a mean of 0.04 and a standard deviation of 3.5 points. Therefore, a

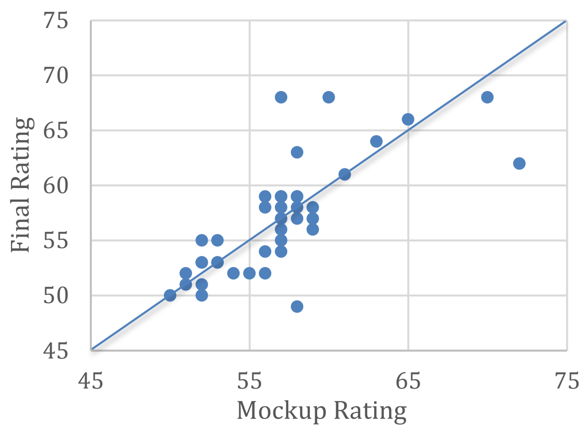


Figure 1 – Predicted versus final impact rating (ISR) for various mockup assemblies.

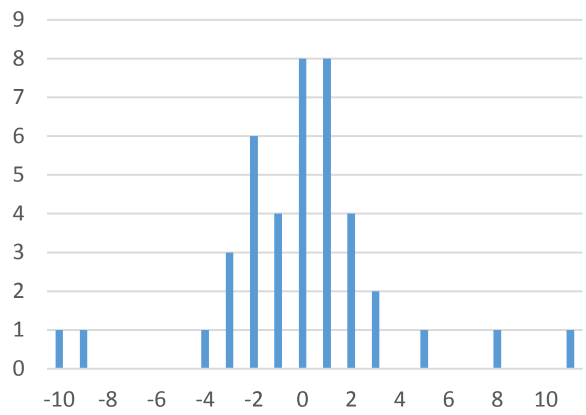


Figure 2. Histogram of difference in ISR between full and mock-up installation (same data as Figure 1).

mockup test would have to exceed the requirement by 4 rating points in order to have a roughly 85% probability of satisfying the requirement. This is highly conservative in too many situations, where there are specific limits that drive the design. Further, in many cases it is not trivial to meet the requirement, and exceeding the requirement by 4 points can be infeasible.

It is easy to think up possible reasons why mockup tests would be inaccurate. The size is of course different, so the loading and excitation of the base structure is different. However, from Fig. 1, there is no apparent trend in the data, and there is roughly equal chance that the mockup can be too high or too low. This implies that the wide scatter is not due to a systematic effect such as small size.

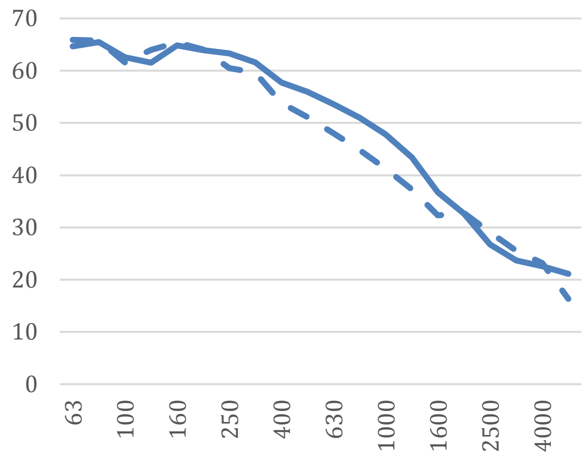
Instead, a better interpretation may be that mockup testing increases the uncertainty in the results. This seems reasonable, and again, it is easy to come up with reasons why this would be so. For example, the position of the mockup on the structure can vary widely. Some of the variation may be explained as the difference between tapping on the center of the floor versus in one corner. However, it is more difficult to provide data to support any of those reasons; for our purposes it is sufficient to note that mockup testing appears, at this point, too imprecise to be a useful predictive method.

3. Improvement in impact insulation

Improvement in impact insulation is measured in the laboratory by consecutively measuring the impact sound pressure level generated on a bare concrete slab and then on the floor topping installed on the slab. The difference in each band is subtracted from a reference spectrum (i.e., the spectrum of a reference bare slab) to account for differences between bare slabs in different laboratories or variation in results of testing a slab.

ASTM standards [2] only include a concrete reference assembly. As wood joists are the structural system for a large portion of residential buildings in the USA, an improvement metric for wood joist framing assemblies is desired. ISO standard 10140-5 [3] defines three wood joist reference assemblies, but these are rather different from systems typically used in the USA.

Preliminary attempts to measure improvement for flooring on wood joist assemblies were mixed. The improvement rating was performed in the same manner as on the concrete slab, except no comparison to a reference assembly was performed since no reference assemblies were defined. If the improvement is solely a property of the floor topping, the same improvement (in third octaves) could be applied to a tested bare slab to predict the



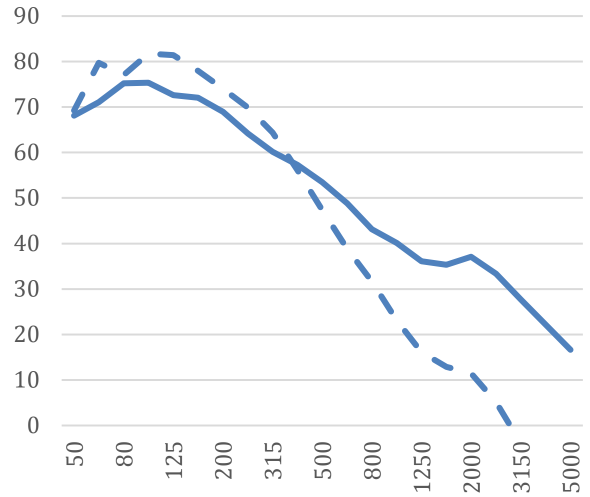


Figure 3. Example measured (solid) and predicted (dashed) impact levels. Predictions made by applying improvement as measured in the laboratory to field tests of wood joist assemblies without flooring (bare gypsum concrete topping)

resultant impact sound level with the floor topping. See Figure 3 for examples.

The difference between predicted and field tested values suggests that greater precision in the process is required. One obvious shortcoming is the lack of a reference assembly for wood joist floors. The authors have conducted several laboratory testing programs where a variety of finish floors were tested on different several assemblies, and analyzed the data with respect to a reference assembly.

3.1 Effect of assembly design

Assembly A was 25.4 mm thickness of gypsum concrete poured directly on 18.8 mm thick OSB sheathing nailed to nominal 2x10 (235 mm deep) wood joists spaced at 406 mm (16 inches) on center. Resilient channel was installed perpendicular to the joists at 406 mm (16 inches) on center, R13 (88.9 mm thick) fiberglass insulation was installed at the top of the joist, and one layer of 16.3 mm (5/8 inch) type “c” gypsum board was screwed to the resilient channel.

Assembly B was the same as Assembly A, except with a 6.2 mm-thick entangled mesh sound control mat below the gypsum concrete.

The program was repeated with a different brand of resilient channel. We refer to the above assemblies with resilient channel 1 as A1 and B1, and similarly A2 and B2 for resilient channel 2.

Eight finish flooring materials were tested in addition to the bare gypsum concrete. Some of the flooring products included a separate foam underlayment pad, and some were glued directly to the gypsum concrete. The materials are listed in Table 1.

Table 1. Finish flooring materials

	Finish flooring material	Underlayment
A	7.8 mm laminate plank	1.5 mm foam
B	15.2 mm Bamboo	1.5 mm foam
C	5 mm engineered wood floor	1.5 mm foam
D	4.1 mm luxury vinyl tile	None
E	3 mm luxury vinyl tile	None
F	6.7 mm hybrid flooring	None
G	3.5 mm vinyl sheet	None
H	3 mm luxury vinyl	1.5 mm foam

Figure 4 shows the effects of different resilient channel. The is one outlier that is not consistent with the remaining data, but otherwise the variations are on the order of 0-3 dB. The wider variations at the high frequencies may be the results of inconsistent background noise levels in the laboratory.

The brand of resilient channel therefore seems to be of minor importance in the measurement of improvement.

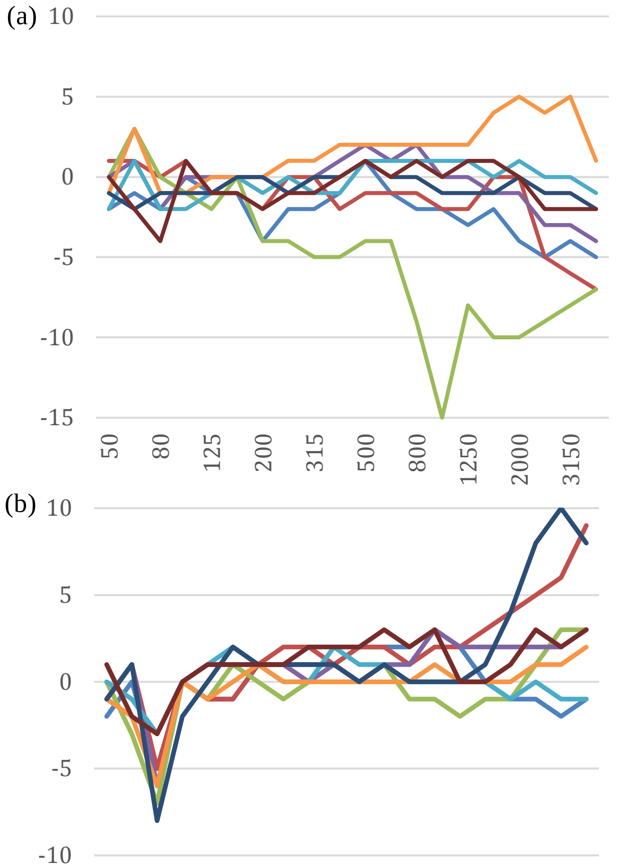


Figure 4(a). Difference in improvement ratings for floor toppings between Assemblies A1 and A2. (b) between Assemblies B1 and B2.

The effect of the sound mat below the gypsum concrete (between Assemblies A and B) was observed by comparing graphs of the impact insulation improvement. The results are shown in Figure 5. With the sound mat under the concrete, the improvement due to some flooring increased and some decreased. The difference was small for higher performing flooring, but was significant for the lower-performing floors. This may be caused by the interaction between the two resilient materials. Introduction of a second sound mat therefore serves only to complicate the measurement.

3.2 Reference Assembly

As discussed above, items such as the additional sound mats below the gypsum concrete should be excluded from the reference assembly. They do not add any information to the measurement. On the other hand, items such as the insulation in the ceiling cavity and the resilient channel for mounting the ceiling, are almost universal in this type of assembly. If they were omitted, the results may not be broadly applicable.

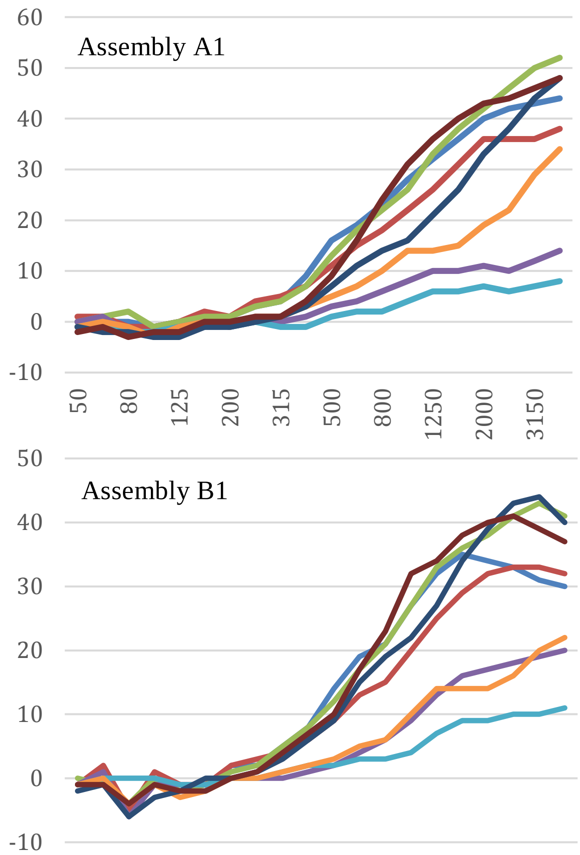


Figure 5. Improvement spectra for flooring for assembly A1 (top) and B1 (bottom). Assembly B has the additional sound mat below the gypsum concrete.

There are three joist types in widespread use in the USA, solid wood, engineered I-joists, and open web trusses. Of these, the trusses were chosen, as they were the most common type tested in the laboratories.

The standard assembly is therefore proposed as 19.1 mm (3/4 inch) thickness of gypsum concrete poured directly on 17.6 mm thick OSB sheathing nailed to 18-inch (457 mm) deep open web wood trusses spaced at 609 mm (24 inches) on center, with resilient channel perpendicular to the trusses at 406 mm (16 inches) on center, R13 (88.9 mm thick) fiberglass insulation was installed at the top of the joist, and one layer of 15.9 mm (5/8 inch) type “c” gypsum board screwed to the resilient channel. See Figure 6.

A number of tests on the bare (exposed gypsum concrete) of the proposed reference assembly were compiled and averaged. The proposed reference

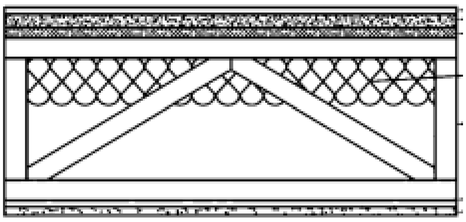


Figure 6. Sketch of proposed mockup assembly.

impact spectrum is given in Table 2, along with the existing ASTM/ISO reference assemblies. This spectrum will continue to be refined with additional tests and samples from other laboratories.

Table 2: Existing and proposed reference spectra

	concrete	ISO 10140-5 C1, C2	ISO 10140-5 C3	Proposed
100	67	78	69	66
125	67.5	78	72	66
160	68	78	75	66
200	68.5	78	78	66
250	69	78	78	66
315	69.5	78	78	66
400	70	76	78	65
500	70.5	74	78	65
630	71	72	78	65
800	71.5	69	76	64
1000	72	66	74	64
1250	72	63	72	64
1600	72	60	69	64
2000	72	57	66	64
2500	72	54	63	63
3150	72	51	60	58

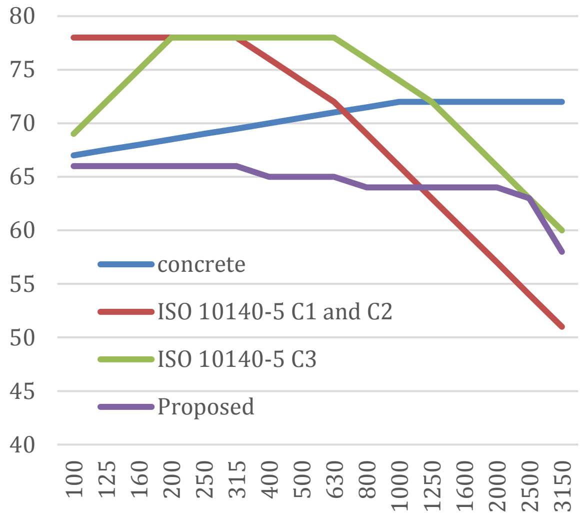


Figure 7. Graph of spectra in Table 2.

4. High-frequency improvement ratings

4.1 Definition

From examination of Figure 5, the improvement due to typical flooring (with and without sound mat) is restricted to the high-frequency region above about 400 Hz. The authors have argued that restricting the bandwidth of the single number rating to have a lower bound of 400 Hz instead of 100 Hz improves the evaluation and rank-ordering of assemblies in general [4]. The reason is that as the performance of the floors improves, the rating begins to be controlled at lower frequencies (below the “knee” in Figure 5) which are not related to the performance of the floor. The high-frequency impact performance is therefore masked. As a consequence, the rating does not correlate well with the isolation of high-frequency impact sources such as hard-soled shoes, dragging furniture, and dropping objects.

Such behavior appears to be general and applies to all assemblies, which is anticipated from theoretical analysis of tapping machine impact noise. Models of the floor covering as a linear elastic layer [5], [6] show that the reduction in impact level due to the floor covering is negligible below the characteristic frequency of the floor covering (which depends on its dynamic stiffness) and increases at a constant rate per octave above this frequency. Although real impact improvement spectra show more complex features, this simple model captures the general trend. The analysis in Ref. 2-4 are based on concrete assemblies, but as Figure 5 shows, the theory appears applicable to the wood structures that are common in the USA.

There is not yet consensus on the use of a narrower bandwidth for a general-purpose rating of impact sound. However, the improvement in impact insulation due to floor coverings is a specific area where the use of a restricted bandwidth rating shows obvious advantage in engineering analysis and judgment of performance. Because floor coverings are usually thin, they cannot achieve very low characteristic frequencies. Both theoretical reasons and testing experience indicate that there is no significant change to the assemblies at lower frequencies. For this type of test, there is simply no point to measuring the improvement at frequencies below about 400 Hz.

The authors therefore proposed [7] a rating called HIIC for High-frequency Impact Insulation Class, calculated in the same manner as IIC except that the lowest frequency band to the reference spectrum 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. The improvement rating is called ΔHIIC and is the difference between the ratings of the difference and reference spectra.

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

4.2 Predictions

The proposed reference assembly was applied to the data set from section 3.1. The ΔIIC and the ΔHIIC ratings were calculated for the different finish floorings, both normalized with the proposed reference spectra in Table 2. The predicted rating is simply the IIC or HIIC of the bare slab plus the ΔIIC or ΔHIIC, respectively, of the flooring. Note that these predictions are based on the single number ratings, not the third-octave bands. The predicted and measured ratings are shown in Figure 8.

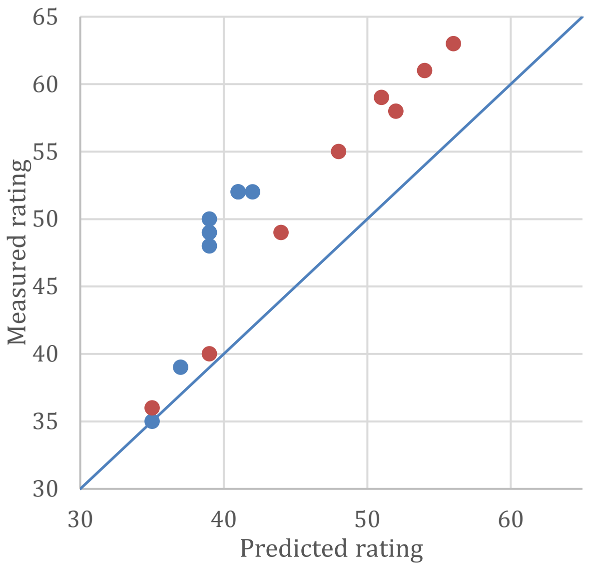


Figure 8. Comparison of measured and predicted ratings IIC (blue) and HIIC (red), calculated from the single number improvement ratings ΔIIC and ΔHIIC

Figure 8 indicates how the IIC rating stops increasing in the 50's, where the IIC rating becomes controlled by frequencies below 400 Hz that are not related to the flooring. By contrast, the HIIC rating continues to improve as the impact level decreases. Figure 8 also shows that using the single-number improvement rating is not yet reliable. However, the relationship is linear, and one hopes that refinements in the reference assembly and/or calculation method may improve the predictive ability.

5. Summary

The data presented show that using mock-up testing to predict the impact performance of flooring is undependable because it lacks sufficient precision. The mock-up procedure introduces too much uncertainty to be useful. The resultant uncertainty in the prediction associated with using a mock-up to determine the performance of a finish floor is too high to allow proper engineering judgment, and requires an impractically large safety factor to achieve confidence in the predictions.

Using the improvement in impact insulation as measured in the laboratory promises to be a more precise and useful method. Significant development work remains. Here we present preliminary studies on defining a wood-framed reference assembly.

The improvement of impact insulation due to floor covering is primarily a high-frequency phenomenon, usually restricted to the range of 400 Hz and above for typical hard surface flooring applied to an existing structure. The existing IIC and $L_{n,w}$ ratings are often determined by frequency ranges that are not affected by floor covering. Since the sound levels at the lower frequencies obscure the improvement at higher frequencies in the calculation of the rating, the existing ratings 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 ΔHIIC for evaluating the improvement of high-frequency impact noise. This rating is shown to be superior to ΔIIC for predicting performance, and also defines the frequency region that is of inherent interest from an acoustical engineering perspective.

Acknowledgement

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