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INVESTIGATION OF A TWO-PARAMETER SYSTEM OF EVALUATING IMPACT NOISE INSULATION

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Abstract

Impact insulation is currently measured using a tapping machine and described with a single number metric, $L'_{n,w}$ defined in ISO 140 and 717, or Impact Insulation Class (IIC) defined in ASTM E492 and E1007. It is well known that these metrics do not correlate well with subjective reaction. Numerous proposals have been made to modify the procedure or floor excitation method in order to develop a metric that better correlates with reaction. However, to our knowledge all such proposals have continued to define the use of a single-number metric to describe acoustical performance. Past research by the authors has shown that in lightweight construction, subjective reaction is much better correlated with low-frequency thudding from footfalls in the 63 Hz octave band than with IIC. Recent experience in concrete buildings (where thudding is not traditionally a concern) indicates that mid and high-frequency impact noise from heel clicks, dragging furniture, etc., are also not well correlated with IIC or $L'_{n,w}$. Experience suggests that the low-frequency impact sound pressure level (ISPL) is influenced by different variables than the mid/high-frequency ISPL, and that the two may be largely independent. If so, it follows that no single-number metric will be able to adequately characterize an assembly. A two-domain system, where the first domain describes the low-frequency performance and the second domain describes the mid/high-frequency performance, is investigated to determine if it results in improved methods for evaluation and rank-ordering of floor/ceiling assemblies.

1. INTRODUCTION

Single-number ratings are popular in acoustics. For example, sound isolation is often expressed in terms of Sound Transmission Class (STC, R_w) and Impact Insulation Class (IIC, $L'_{n,w}$), and HVAC equipment noise is often defined by Noise Criteria (NC or NR) or Room Criteria (RC). Although the exact methods differ, the single-number rating for all of these examples is found by fitting the octave or third-octave band data to a standard curve.

Single-number ratings have obvious limitations, and detailed octave-band data is generally required for proper acoustical design work. However, they have still proven to be useful in many cases. For example, STC does a generally acceptable job of ranking assemblies in order of increasing airborne noise isolation. However, the same cannot be said of the impact noise isolation metrics, which is the subject of this discussion.

2. IMPACT NOISE INSULATION METRICS

2.1 Overview

The two common impact noise insulation metrics are IIC defined in ASTM E492 and E989, and $L'_{n,w}$ defined in ISO 140 and 717. The ASTM and ISO standards differ in the details of their calculation procedures, but these differences are not significant for the purposes of this discussion. We will treat them conceptually as a single metric and refer to them collectively as IIC.

This metric has been in use from the early 1960's in the United States, and earlier in Europe, and from the beginning there was criticism that this metric did not correlate well with subjective reaction (see [4] for an overview). In recent years investigation has focused on the low frequency thudding in lightweight joist construction [1–3], [5]. It has become well accepted in the acoustical community that IIC is not "well behaved" like STC, and that IIC ratings are often uncorrelated or even reversed with respect to subjective reaction.

Attempts have been made over the years to modify or replace this metric with one that correlates more closely with subjective reaction. Some have proposed changing the source machine, such as the tire machine and rubber ball used in Japan. Others have proposed changes the measurement or calculation procedure [6]. In general, however, all of these proposed systems have retained single-number metrics as the basis for comparison.

Annex A of ISO 919-2:1996 introduces a second "spectrum adaptation term," but this is not a separate rating but a modifier which is added to the $L'_{n,w}$ so that the result is still a single-number metric. Obviously it would be simpler if a suitable single-number metric can be found, but we question whether that is possible.

2.2 Qualitative comparison with STC

Good correlation between airborne sound ratings (STC, R), which are similar to measured noise reduction (NR), and subjective ratings of airborne noise isolation can be attributed to the fact that transmission loss (TL) and NR curves have the same general shape. Aside from some dips caused by resonances or leaks, the TL and NR increases with frequency. There are very few assemblies which do not behave in this manner.

By contrast, Figure 1 shows three actual impact sound pressure level (ISPL, i.e., the sound pressure level in the room below while the tapping machine is operated on the floor above) spectra for three different floor assemblies. One is a concrete slab building without resilient flooring or underlayment; the other two are different wood joist buildings with different floor coverings.

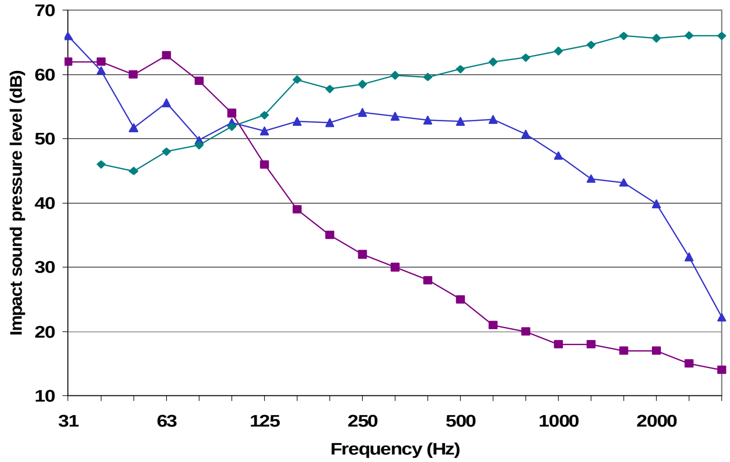

Figure 1. ISPL of three common floor/ceiling assemblies. u–concrete building, hard surface flooring; p–wood joist building, hard surface flooring; n–different wood joist building, carpet

These are not anomalous spectra but typical of assemblies commonly encountered. Unlike transmission loss graphs, which in general always slope up from low frequency to high, the ISPL spectra can slope up, or be flat, or slope down. This raises doubts as to whether any single-number metric after the model of STC is possible.

3. TYPES OF IMPACT NOISE COMPLAINTS

Based on a survey of the literature, along with experience in retrofit projects and litigation, it appears that impact noise complaints can be divided into two broad classes: low frequency or thudding, typically caused by footfalls in lightweight wood or steel joist buildings; and mid/high frequency, or clicking, typically caused by heel clicks, hard soled shoes, dropping objects, dragging furniture, etc.

3.1 Low frequency impact noise

Low frequency impact noise, which is almost exclusively thudding from footfalls, generates highest noise levels below 100 Hz, and almost all the energy is below 200 Hz. Much of the literature discussing the inadequacy of the existing impact noise metric are based on thudding complaints in lightweight construction [5]. The authors' previous investigation indicates that the standard tapping machine can be used to predict the low frequency levels from footfall, and that subjective reaction is much more strongly correlated with the ISPL in the bands below 100 Hz than with IIC [1–3].

In the authors' opinion, the low frequency ISPL is most dependant on the structural stiffness of the base assembly. Other variables in the construction can affect the low frequency ISPL including ceiling connection details and thickness of insulation. Low frequency complaints generally occur in lightweight wood or steel joist construction, where the structural deflection with footfall is much larger than in concrete slab buildings. Tellingly, finish floor material and resilient underlayment materials traditionally installed for these applications are of limited effectiveness against this complaint.

3.2 High frequency impact noise

Heel clicks and similar events occur mainly in the 500 and 1000 Hz octave bands. The ISPL at these frequencies is relatively independent of structural factors and strongly dependent on finish floor material and presence and type of resilient underlayment, presence of insulation in a joist or ceiling cavity and the ceiling attachment method.

While it is not surprising that IIC does not perform well for impact sounds below 100 Hz, the lower limit of the reference curve, we find the IIC also does not adequately evaluate or rank-order assemblies in terms of their mid and high frequency performance. As will be demonstrated below, the ISPL between 100 and 400 Hz controls the IIC value, and therefore changes in the mid/high frequency performance do not affect the rating.

4. FIELD TESTING EVALUATION

4.1 Field testing

Figure 2 shows the results of a large number of mock-up tests with hard surface flooring over a variety of different underlayment materials. The goal of this exercise was to rank-order the materials so that an informed decision could be made. The IIC rating varied from 57–59, and without looking at the spectra, one would reasonably conclude that the materials were roughly equivalent. However, there were significant differences in loudness between some of the assemblies. There were differences of over 10 dB at some of the frequency bands of interest for heel clicks.

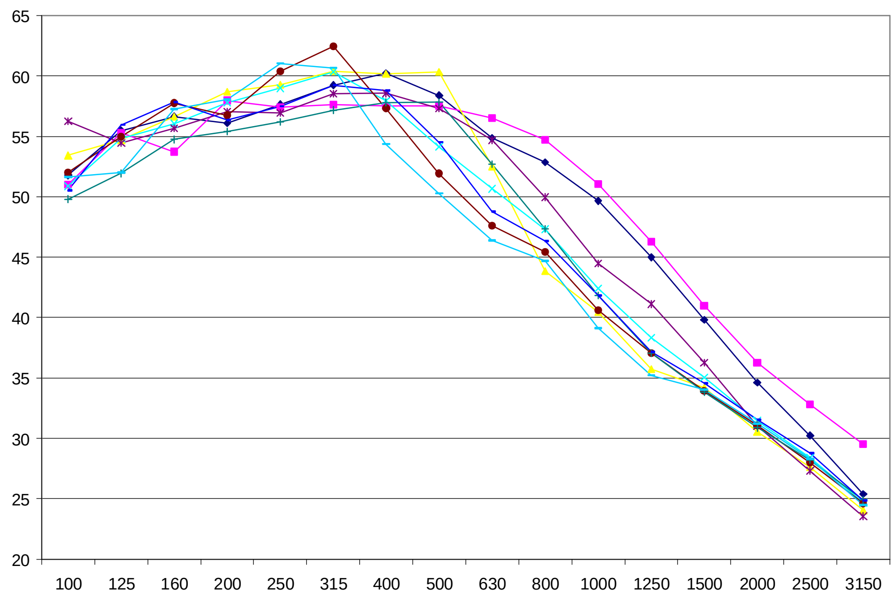

Figure 2. ISPL spectra of hard surface flooring over a variety of resilient underlayment materials.

If the IIC rating was calculated excluding the bands below 400 Hz, then the modified IIC ratings range from 57 to 65. The revised ratings not only have an increased spread which relates to the differences in loudness, but the ratings also correctly rank-ordered the assemblies as compared with the subjective rankings of listeners in the receiving room.

4.2 Effect of resilient materials

By their nature, resilient flooring (i.e., carpet, cushioned vinyl) and hard surface flooring over resilient underlayment materials (traditionally installed in residential applications) are effective only in the mid/high frequencies. Figure 3 shows the average reduction in ISPL of a flooring system when a resilient flooring or a resilient underlayment is added to the base assembly. This graph combines approximately 100 field tests on over 10 projects, and includes 12 different resilient products and many different types of finish floor. It includes both wood and concrete buildings and various ceiling conditions. The results are remarkably consistent and the 95 precent confidence intervals are quite small at the low frequencies. Figure 3 indicates quite clearly that resilient flooring systems most effective above about 400 Hz.

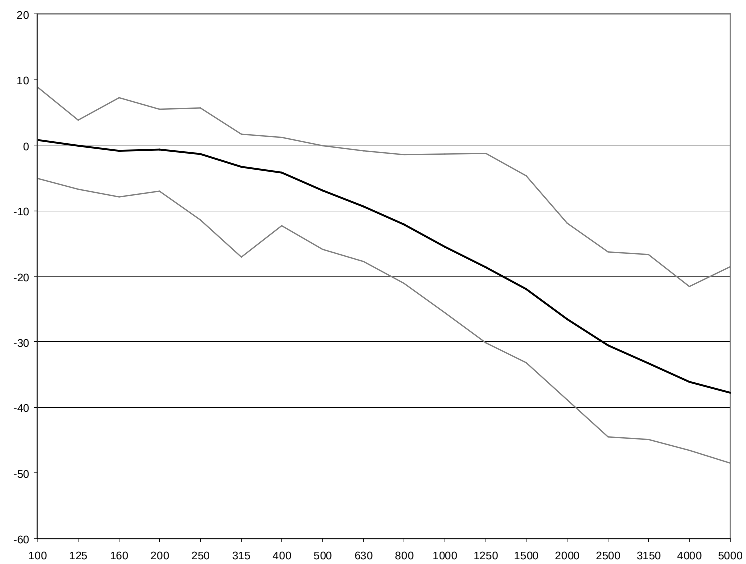

Figure 3. Average reduction in ISPL when resilient material is added to floor system. Thin lines are 95 percent confidence intervals.

5. ANALYSIS

As discussed, complaints can occur from excessive ISPL at both low frequencies and mid/high frequencies. Structural parameters only affect the low frequencies; resilient materials only affect the mid and high frequencies. (Some design items, such as resilient ceiling attachment and presence of insulation can affect both low and high frequency isolation.) Therefore, in any given assembly, the impact insulation at low and high frequencies can be adjusted independently, at least to a substantial degree. If so, this implies that it is impossible to adequately characterize this assembly with a single number metric like IIC.

This may be best illustrated by separating the low frequency and mid/high frequency components of the ISPL spectrum produced by the standard tapping machine, and graphing them as independent parameters on a scatter plot. Figure 4 shows a number of assemblies graphed in such a manner, with high frequency performance on the x-axis and low frequency on the y-axis (greater values are better).

The scatter across the plot is wide, and there is no obvious way to relate the points, i.e., no best-fit line can be drawn through a significant percentage of the data points. Therefore, no single number can characterize the data set, and the adequate characterization of impact noise insulation may require a two-domain solution.

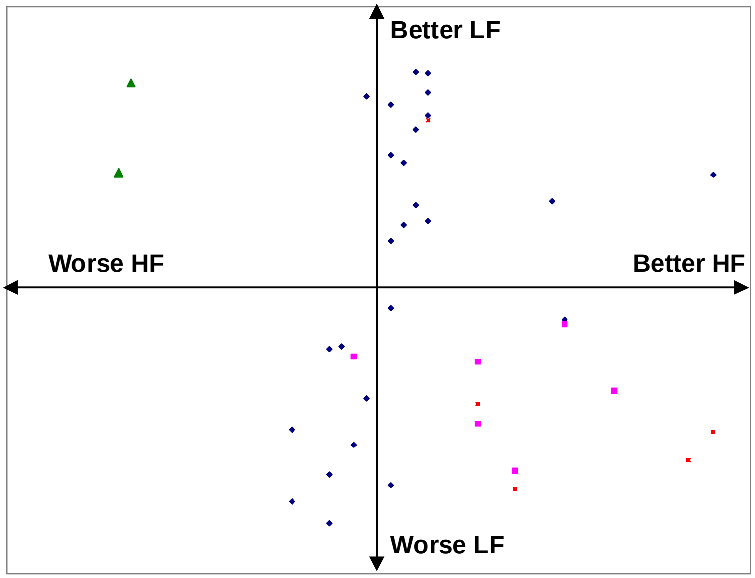

Figure 4. Scatter plot of high-frequency vs. low frequency impact insulation of various assemblies.

6. CONCLUSIONS

It is well known that IIC is not an adequate metric for evaluating impact noise insulation. We go further and suggest that *any* single-number approach will fail to adequately evaluate impact noise insulation. This is because the shape of an ISPL spectrum can vary widely among commonly-encountered assemblies (unlike transmission loss spectra). If this is correct, then the efforts to improve IIC or any other single number metrics measured over a wide range of frequencies by using a different standardized curves, extending the frequency response, or even changing the source, will not adequately define the acoustical performance of the assemblies. The two domain approach appears to better evaluate the performance of the assemblies. Further, our analysis appears to indicate that a two-domain approach can successfully characterize the subjective acceptability of an assembly. The exact definition of those metrics and the most useful methods of measuring and calculating them are under investigation.

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