A new metric to quantify and evaluate low frequency impact noise

John J. LOVERDE[1]; Wayland DONG[2]

[1, 2] Veneklasen Associates, United States of America

ABSTRACT

Low frequency footfall noise ("thudding") is a common source of complaints in lightweight (timber) joist-framed multifamily projects. Previous work by the authors has indicated that the low frequency impact sound pressure levels (LFISPL) from a standard ISO tapping machine are highly correlated with occupant reaction. It remains to translate the raw LFISPL data into a useful single number metric that maintains the high correlation with subjective reaction, provides adequate dynamic range to distinguish the performance of different assemblies, and is conveniently scaled. This paper introduces Low-frequency Impact Rating or LIR, a new metric to quantify and evaluate low frequency impact noise.

Keywords: Low-frequency, Impact, Metric I-INCE Classification of Subjects Number(s): 51.5

1. INTRODUCTION

Low-frequency thudding from footfall is a common complaint in multifamily housing where lightweight, joist (timber)-framed floor assemblies are used. It has long been documented that the current measurement and rating metrics do not correlate well with subjective reaction (1, 2). Work has continued to attempt to evaluate the means by which to evaluate the low frequency impact sound from one dwelling to another.

Some of the results in section 2 have been presented during past meetings of the Acoustical Society of America, including Cancun in 2002 (3) and Rhode Island in 2006 (4), and also at Inter-noise 2004 (5). Some of the discussion in section 3 was presented during the 2013 meeting of the Acoustical Society of America in San Francisco (6).

2. LOW FREQUENCY IMPACT NOISE AND COMPLAINTS

2.1 Existing Measurement Procedure

Field impact noise isolation tests are defined in ISO 140 and ASTM E1007, and the procedures are similar between the two standards. Both use the same tapping machine on the floor of the assembly to be tested. The resultant impact sound pressure level (ISPL) in third-octave bands from 100 to 3150 Hz are measured in the receiving room below. Normalization to a standard amount of absorption or reverberation time may be performed but is not pertinent to this discussion.

Single-number ratings derived from the third-octave measurements are defined by ISO 717-2 and ASTM E989. The measured values are compared to a reference curve and the unfavorable deviations (i.e., when the measured values exceed the reference) are summed, with the total deviations not to exceed 32 dB. ASTM E989 additionally requires that the deviation in any one third-octave band not exceed 8 dB. The ISO laboratory rating is called $L_{n,w}$; the corresponding ASTM rating is IIC (Impact Insulation Class), and is inverted compared with $L_{n,w}$ so that higher ratings indicate lower impact sound pressure levels and hence higher insulation.

ISO 717-2, Annex A, defines an additional “spectrum adaptation term” C_I, which is an unweighted linear sum of the sound pressure levels from 125 to 2000 Hz (third octave bands), minus 15 dB. The Annex also suggests an additional calculation over a frequency range of 50 to 2500 Hz, designated $C_{I,50\text{-}2500}$. The intentions of the C_I metric are to better account for “level peaks at single (low)

[1] jloverde@veneklasen.com
[2] wdong@veneklasen.com

frequencies” typical of wood structures, and to better characterize the A-weighted impact levels from walking (7).

2.2 Low-Frequency Thudding From Footfall

Like many acousticians working on multifamily projects, over the last 20 years the authors have had considerable experience attempting to improve the impact insulation in buildings with an unexpected number of complaints despite seemingly adequate IIC ratings. Analyzing data and listening to occupants indicated that the complaints were related to low frequency “thudding” or “thumping” noise due to footfall. Because the existing metrics used within the United States of America (USA) do not require measurement below 100 Hz, it was not surprising that the results did not adequately characterize the amount of such thudding or the anticipated reaction of the occupants. In order to determine what metrics do characterize the thudding and hopefully correlate with subjective reaction, an informal research program was undertaken.

Although measurements using the tapping machine are designed to range from 100 Hz and up, the spectra of the standard tapping machine on carpet or resilient flooring is very similar to a human walker at frequencies below 100 Hz (2, 8). Therefore, the tapping machine potentially allows for the evaluation of low frequency impact noise, which is far easier and more repeatable than a live walker or some of the other testing methods currently being investigated, which would both require additional measurements from the current standard.

Field impact test data was compiled for 14 assemblies where impact noise was the predominant concern. Subjective acceptability was quantified based on the reports of the owners, operators, and/or building managers as to the percentage of complaints. This is not scientifically rigorous, of course, but there are few options for this type of evaluation. We attempted to reduce bias as much as possible by ranking the assemblies prior to plotting the data, and did not subsequently modify the rankings.

The non-normalized ISPL was measured in third-octave bands from 20 to 100 Hz. Summations of adjacent third-octave bands with various bandwidths were also calculated. (For example, a bandwidth of two would sum the 20 and 25 Hz bands, the 25 and 31 Hz bands, etc., up to 100 Hz.) The correlation coefficient between subjective reaction and the low frequency ISPL in the various bands was then calculated. The highest correlation was found to be with the sum of the 50, 63, and 80 Hz bands, which of course is also the 63 Hz octave band. We refer to this level as LFISPL for low-frequency impact sound pressure level. The correlation is not strongly dependent on bandwidth.

Figure 1 shows the relationship between AIIC and subjective reaction (blue triangles). Although there is obviously a correlation between the two variables, the wide scatter of points is a representation of the problems with AIIC in practice. Note that two projects indicated by the green arrow had the same subjective rating but varied by 25 AIIC points! Figure 1 also shows the relationship between LFISPL and subjective reaction, which is obviously a tighter relationship.

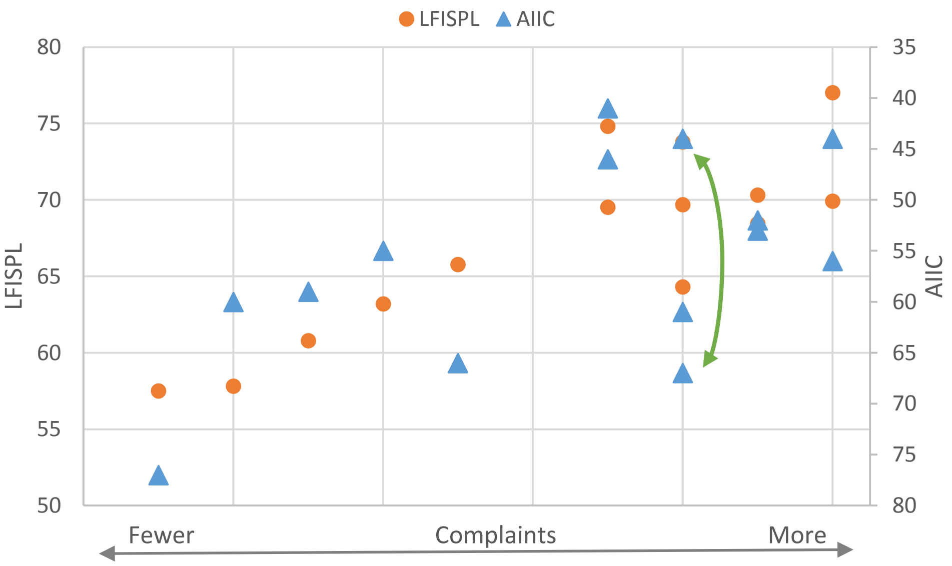

Figure 1 – Relationship between rating and subjective reaction for LFISPL and AIIC. The green arrow highlights two projects that had the same subjective rating but varied by 25 AIIC points.

To quantify the difference, Figure 2 shows the coefficients of correlation (R) and determination (R^2) with subjective rating for AIIC and LFISPL, as well as for $L_{n,w}$ with and without spectrum adaptation terms and A-weighted ISPL. The R^2 for AIIC and similar metrics is low, about 0.3, which is a quantification of the wide scatter in the points in Figure 1. By contrast, the R^2 of LFISPL is more than twice as high at 0.72.

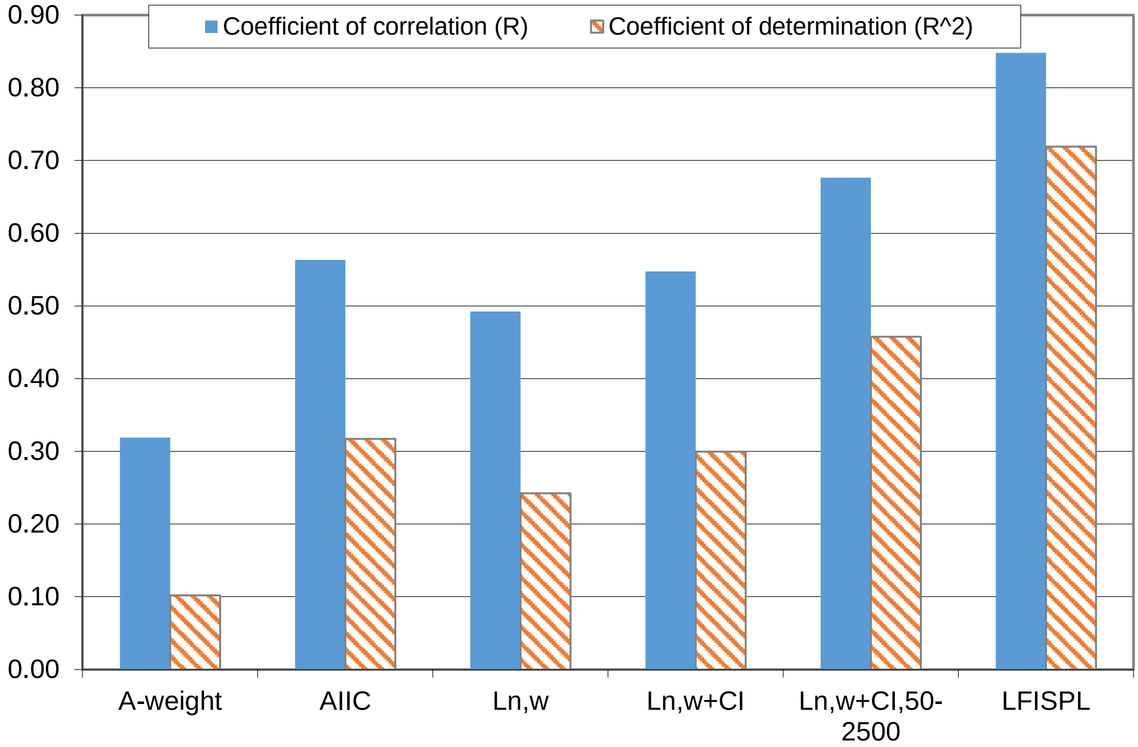

Figure 2 – Coefficients of correlation and determination between various metrics and subjective reaction

2.3 LFISPL Measurement

Based on the data, it is obvious that for lightweight, (timber) joist-framed assemblies, the LFISPL is a better indication of perceived isolation than the existing metrics. Note that these tests include both hard surface and carpeted floors. For these types of projects, low frequency thudding is the most important factor in determining subjective reactions. For about the last 12 years, therefore, Veneklasen Associates' policy has been to routinely measure ISPL down to 50 Hz, a full octave below the requirement of the standard, when performing impact insulation tests. As hoped, we have found LFISPL to be useful in evaluating and designing floor-ceiling assemblies where footfall thudding is a concern. The value of this is that the measurement can be accomplished without requiring the use of a second source or additional testing procedures.

3. PROPOSED METRIC

3.1 Desired Characteristics

LFISPL is straightforward to measure but is not suitable for use as a rating metric. A metric should have higher values indicating better isolation and therefore a better assembly. It should have a suitable range of values so that different assemblies are easily compared. In other words, the gap between good and poor assemblies must be large enough to easily distinguish despite measurement uncertainties. Finally, the numerical value of the metric should be convenient.

3.2 Scale

To determine the scale of the metric, we note that field testing experience shows that LFISPL varies from about 50–80 dB for common floor-ceiling assembles. Figure 3 shows equal loudness contours, with the range of interest of 50–100 Hz and 50–80 dB highlighted. The contours in this region are much closer together than at mid frequencies. A given change in sound pressure level corresponds to approximately twice the loudness difference as the same change in sound pressure level at 1000 Hz. While many are familiar with the rule of thumb that a 10 dB change in level corresponds to a doubling of loudness, for LFISPL it is only a 5 dB change (approximately) per a doubling of loudness. To account for this difference, the low frequency metric should be expanded by approximately a factor of two, so that a 1 dB change in level corresponds to a difference of 2 rating points.

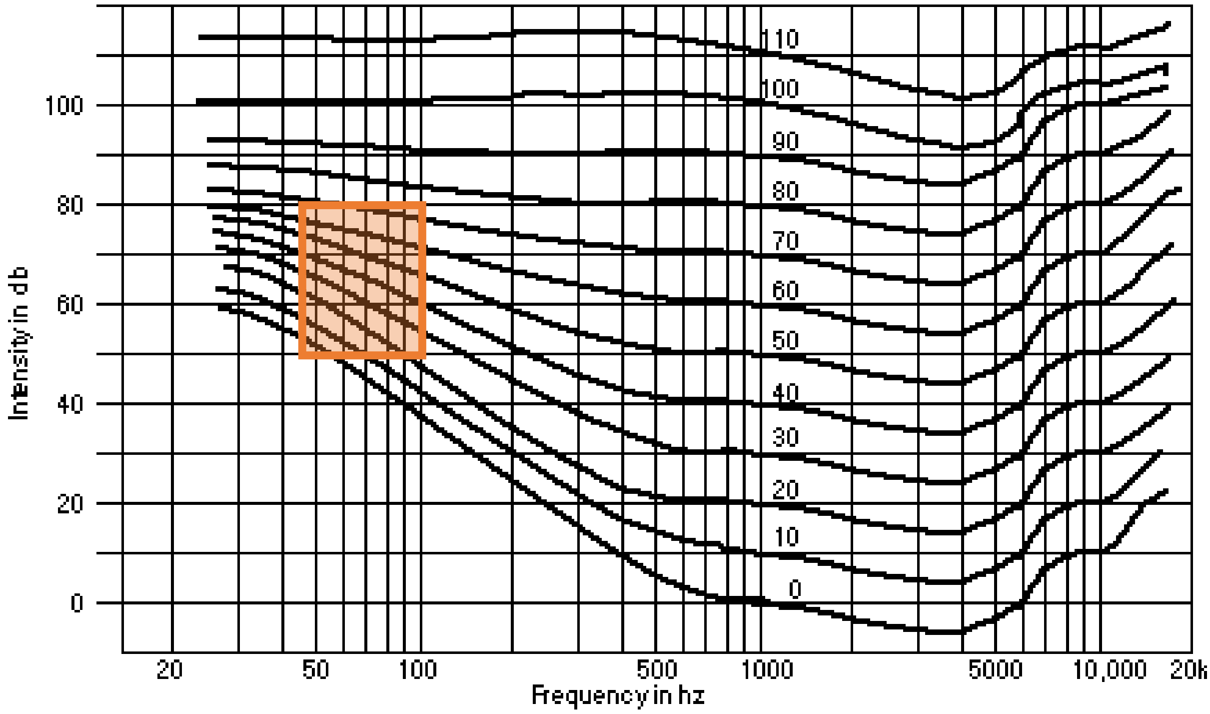

Figure 3 – Equal loudness contours with the region of interest highlighted.

3.3 Numerical Value

The overall numerical value of the metric should be convenient. In the USA, it is common for building codes and other such requirements to assign a minimum value of STC 50 to assemblies that separate residences in multifamily buildings. It would be desirable, therefore, for a rating of 50 to correspond to a minimum level of performance. For assemblies that offer better isolation than code minimum, we use the descriptive identifiers Acceptable and Preferred, which are taken from the International Code Council Guidelines for Acoustics (9). It would be convenient for a rating of 60 to correspond to Acceptable and a rating of 70 to correspond to Preferred.

3.4 Low-Frequency Impact Rating (LIR)

Because we have been measuring LFISPL for many years, we have been able to associate LFISPL with the acceptability of various assemblies. This is based on a combination of listening to both tapping machine and footfall sources, LFISPL measurements, and discussions with occupants, building managers and owners regarding complaint histories. We have observed that an LFISPL exceeding 70 dB generates a large percentage of complaints, while an LFISPL below 60 dB is almost universally acceptable.

Therefore, we propose a new metric called Low-frequency Impact Rating or LIR, defined as

$$LIR = 190 - 2 * LFISPL \tag{1}$$

where LFISPL is the unweighted sum of the 50, 63, and 80 Hz third-octave bands measured using the same testing procedure as defined within the existing metrics (ASTM E1007 or ISO 140-7).

With the definition in Eq. (1), the LIR is 50 for a minimum level of performance, similar to the STC 50 requirement of the building code within the USA. LIR 60 is an Acceptable level of performance that will satisfy most occupants in most situations, while LIR 70 is a Preferred level of performance that will generate very few complaints and is suitable for luxury projects.

The overall range in LIR, based on applying it to the thousands of field tests in our database, is approximately 30–100. The very high ratings are poured, massive and stiff concrete slab buildings, and these ratings reflect the fact that thudding is not a common issue in that type of construction. The LIR for wood-joist assemblies typically range from the high-30's to the low-70's. This rating therefore has the intended wide range to more easily distinguish the quality of the acoustical assembly.

Note that the LIR is only defined for field testing. At this time there is no equivalent procedure for laboratory testing.

4. CONCLUSIONS

While it is widely known in the acoustical community that low frequency thudding from footfall is a common source of complaints, and that the existing IIC and $L_{n,w}$ metrics do not adequately characterize such noise, a qualitative means of measuring and evaluating such noise has not emerged using the tapping machine. We propose a new metric called LIR which provides a rating system for low-frequency impact noise that is easy to understand for those already familiar with metrics such as STC. The measurement method is the same as the existing tapping tests, except at a lower frequency; the calculation method is simple. The new metric can therefore be measured simultaneously with the existing metrics with minimal additional work. LIR is designed with a wide range for improved ability to differentiate assemblies, and a convenient numerical value. Based on historic data, the LIR is an effective means for better evaluating acoustical performance of floors as they relate to occupant satisfaction.

ACKNOWLEDGEMENTS

The authors wish to thank Veneklasen Associates for their continued support of this research.

REFERENCES

1. T. Mariner and H. Hehmann, "Impact-Noise Rating of Various Floors," J. Acoust. Soc. Am. 41(1), 206-214, 1967.
2. Warren Blazier and Russell DuPree, "Investigation of low-frequency footfall noise in wood-frame, multifamily building construction", J. Acoust. Soc. Am 96, 1521-1532, 1994.
3. John J. LoVerde and Wayland Dong, "The Isolation of Low Frequency Impact Sounds in Hotel Construction," J. Acoust. Soc. Am. 112 (5) 2201, 2002.
4. John J. LoVerde and Wayland Dong, "Design Parameters for Impact Sound Insulation in Lightweight Wood and Steel Structures," J. Acoust. Soc. Am. 119 (5) 3220, 2006.
5. John J. LoVerde and Wayland Dong. Measurement and Evaluation of Low Frequency Impact Noise in Lightweight Wood Floor Ceiling Assemblies. INCE. INTER-NOISE 2004, 33rd International Congress and Exposition on Noise Control Engineering Proceedings. Paper 296. P.167, 2004.
6. John J. LoVerde and Wayland Dong, "Development of a low-frequency impact noise metric," J. Acoust. Soc. Am. 134 4083. 2013
7. ISO 717-2:1996, Annex A, p 6, 1996.
8. A. C. C. Warnock, "Low Frequency impact sound transmission through floor systems," Proc. Inter-Noise-92.
9. International Code Council, ICC G2-2010 Guideline for Acoustics, 2010.