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A New Rating Method for Low-Frequency Impact Noise

Residents, building owners, architects and acoustic consultants are rightly concerned about footfall noise transmission through multi-family building floor/ceiling assemblies. By code, most projects in the USA are required to meet a minimum design rating of IIC 50; AIIC 45 if field tested. However, no matter how high the rating, residents in wood frame buildings often complain that low-frequency, or "thudding" footfall noise is a problem. Unfortunately, the IIC rating system does not evaluate impact noise at frequencies below 100 Hz. In this paper, we show that footfall noise is present at audible frequencies below 100 Hz, how this footfall noise can be replicated more objectively using ball drops or a tapping machine, and how measured impact noise might be used to develop a single number rating for low-frequency impact noise insulation of field tested floor/ceiling assemblies. The findings presented are not meant to be taken as final results, but rather a summary of progress made to-date for work that is under-development.

Short Review of Current Impact Testing Method

Impact insulation tests in the United States are typically performed per ASTM standard E1007: Standard Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling Assemblies and Associated Support Structures. In short, the standardized method involves making measurements of tapping machine impact noise in a receiver room directly below the impact source and normalizing the results based on measurements of sound absorption in the receiver room. The results are evaluated at 1/3 octave band frequencies between 100 Hz and 3,150 Hz. Using ASTM standard E989: Standard Classification for Determination of Impact Insulation Class (IIC), the results are curve fit and an IIC single number rating is determined.

A few reasons the IIC rating does not evaluate impact noise below 100 Hz are:

1. Test reproducibility is reduced.
2. There is increased error in measuring low frequency noise in small rooms.
3. It is difficult or impossible to accurately measure reverberation time at low frequencies inside small rooms, and therefore the impact noise results cannot be normalized.

We expect any new method for evaluating low-frequency impact noise needs to either accept or account for these shortcomings.

Footfall Impact Noise

ESI has performed measurements of footfall noise in wood frame buildings with both soft and hard surface floorings. For this review, we will focus on measurements made for one condominium project. The following describe the footfall noise measurements:

- There were six floor/ceiling assemblies tested. Each assembly had the same base construction consisting of OSB subfloor, open-web trusses, blown-in insulation, resilient channel and two layers of gypsum board. Three assemblies were finished with laminate flooring over 1” thick gypsum concrete and ⅜” thick sound mat, and the other three were finished with carpet and pad over 1-⅜” thick gypsum concrete.
- One person walked on each test floor while impact noise levels were measured in the units directly below. The walker was wearing leather soled shoes (see Figure 1) and used a metronome to maintain a brisk walking pace of 140 steps per minute.

Figure 1 – Photo of the walker source.

- Using a moving microphone method, walker impact sound pressure levels were measured for a 60 second period and evaluated as L_{eq} (i.e., the equivalent continuous sound pressure level for the test period measured in pascals, and then converted to decibels).

Figure 2 shows a plot of the average background noise levels and the walker impact sound pressure levels on both the laminate and carpet finished floors, each an average of the three tests per flooring type. Only the results at audible frequencies below those used for the IIC rating system (i.e., 20 Hz to 80 Hz) are plotted.

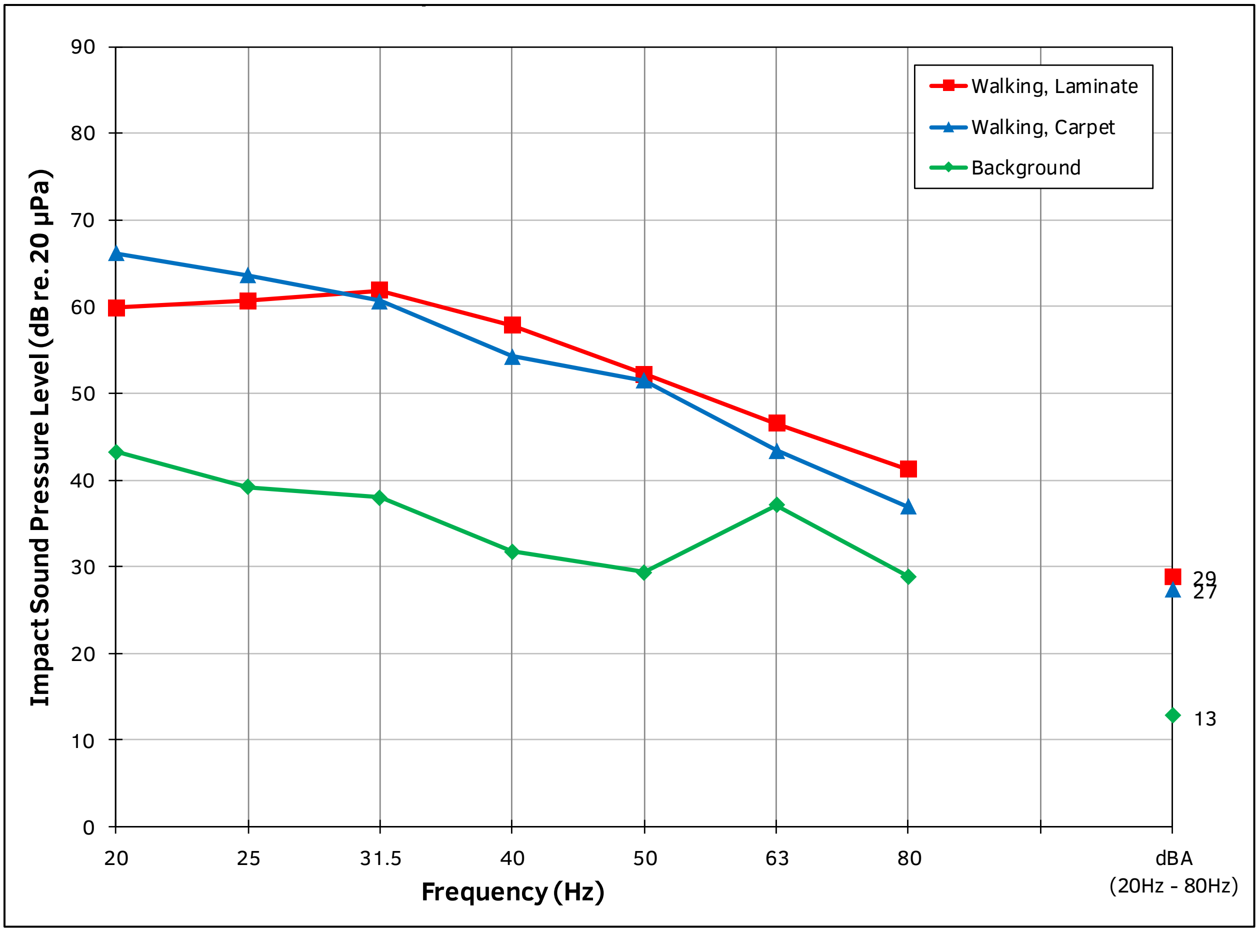

Figure 2 – Plot of measured walker impact sound pressure levels.

We can draw the following conclusions from these results:

- Low-frequency footfall impact noise was audible at frequencies less than those measured using the IIC rating system.
- At the evaluated frequencies, the impact sound levels on the two flooring types were no more than 6 dB different at any particular frequency.
- When an overall A-weighted level is calculated for each impact test that only includes impact sound pressure levels at the 20 Hz to 80 Hz frequencies, the results were within 2 dBA of each other.

Ball Drop Impact Tests

Using human walkers as a noise source inherently has many issues when trying to perform reproducible tests. A few of the walker-to-walker variations include weight, steps per minute, gait and shoe type. A more objective test that provides similar low-frequency impact noise results to walking is a ball drop method. When dropping the same ball from the same height and averaging the impact sound pressure levels (ISPLs) over multiple drops, this method provides more reproducible results than the walking test.

ESI performed ball drop tests on the same floors used for the walker tests. The following describe the ball drop impact noise measurements:

- A 5.5 pound soft weight ball (shown in Figure 3) was used as the impact source.

Figure 3 – Photo of the ball drop source.

- The ball was dropped from a height of 12 inches above the floor.
- Using a moving microphone method, 15 individual ball drops were measured. The frequency content of each measurement was evaluated as bin-by-bin L_{Fmax} levels (i.e., the maximum sound pressure level at each 1/3 octave band frequency during the measurement period using a fast time-weighting). The results of all 15 measurements were then averaged to produce a single set of ball drop ISPLs.

Figure 4 shows a plot of the average ball drop ISPLs on both the laminate and carpet finished floors along with the background noise levels.

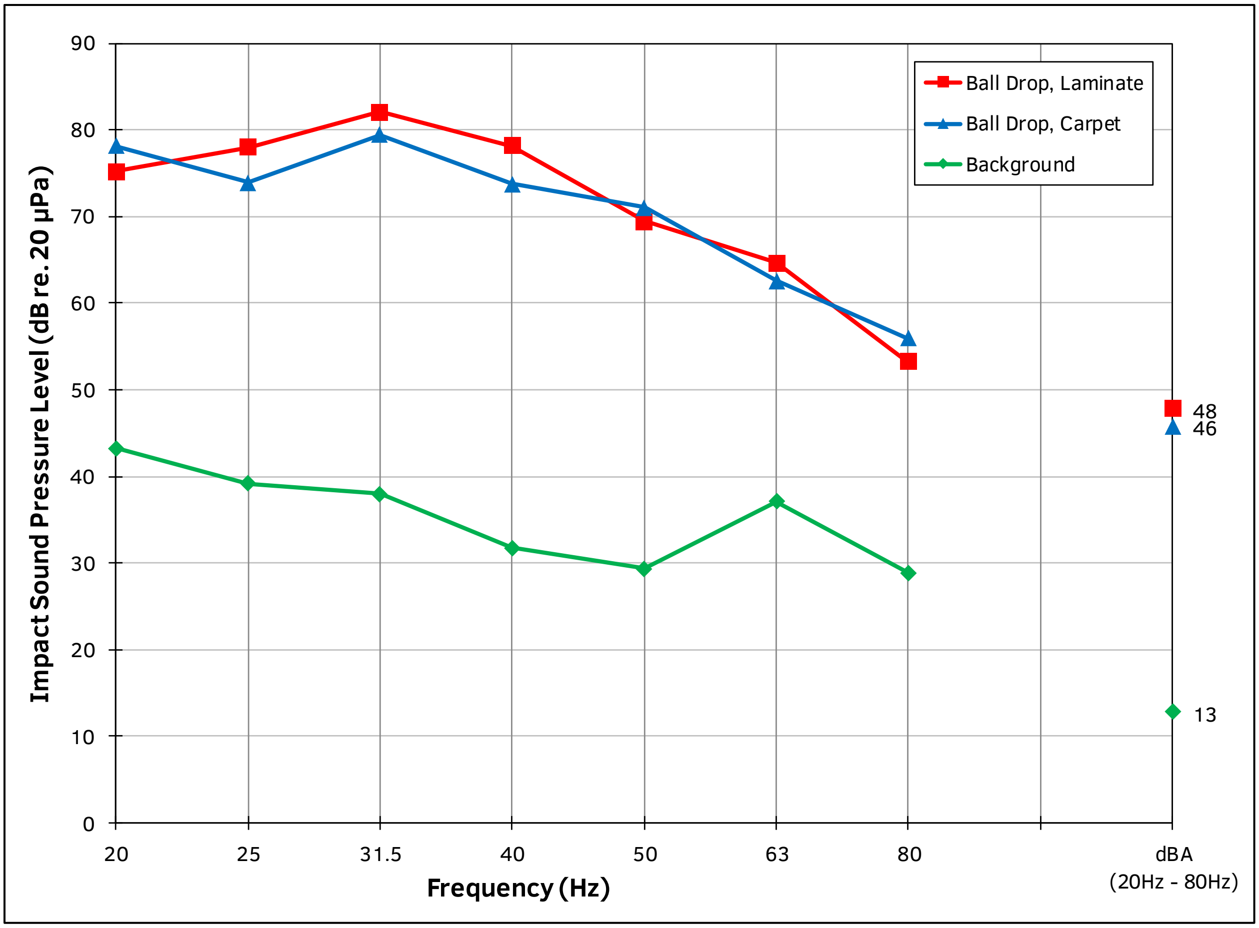

Figure 4 – Plot of measured ball drop impact sound pressure levels.

We can draw the following conclusions from these results:

- The ball drop L_{Fmax} levels were 10 to 20 dB louder than the walker L_{eq} levels, but both sets of ball drop results increased in noise level with decreasing frequency at a similar rate as the walker tests. They also plateaued near 31.5 Hz in a similar fashion as the walker tests.
- Like the walker tests, the ball drop ISPLs were very similar for both the laminate and carpet results, with no deviation at any one frequency of more than 5 dB.
- Looking at the 20 Hz to 80 Hz overall A-weighted levels, the results were within 2 dBA of each other, which is the same as the walker test results.

Tapping Machine Impact Tests

The source used to perform impact insulation tests in accordance with ASTM standards is the tapping machine (see Figure 5). This source drops five metal hammers onto the floor surface at a rate of about 10 drops per second. If a single number rating for low-frequency impact sound transmission were developed using this source, every consultant in the USA could evaluate low-frequency impact noise as long as standardized methods were followed. This would be much preferred to performing an all new test with either walkers (which couldn't be standardized) or ball drops. Because the tapping machine is a standardized impact source, reproducibility of results may also be less of an issue than the walker or ball drop sources.

Figure 5 – Photo of the tapping machine source.

ESI performed tapping machine tests on the same floors used for the walker and ball drop tests. The following describe the tapping machine impact noise measurements:

- The tapping machine was used as the impact source and located near the center of each tested floor.
- The testing methodology followed the requirements of ASTM standard E1007-16: Standard Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling Assemblies and Associated Support Structures.
- Using a moving microphone method, the tapping machine ISPLs were measured for 60 second periods and evaluated as L_{eq}.

Figure 6 shows a plot of the average tapping machine ISPLs between 20 Hz and 80 Hz for the laminate and carpet finished floors along with the average background noise levels.

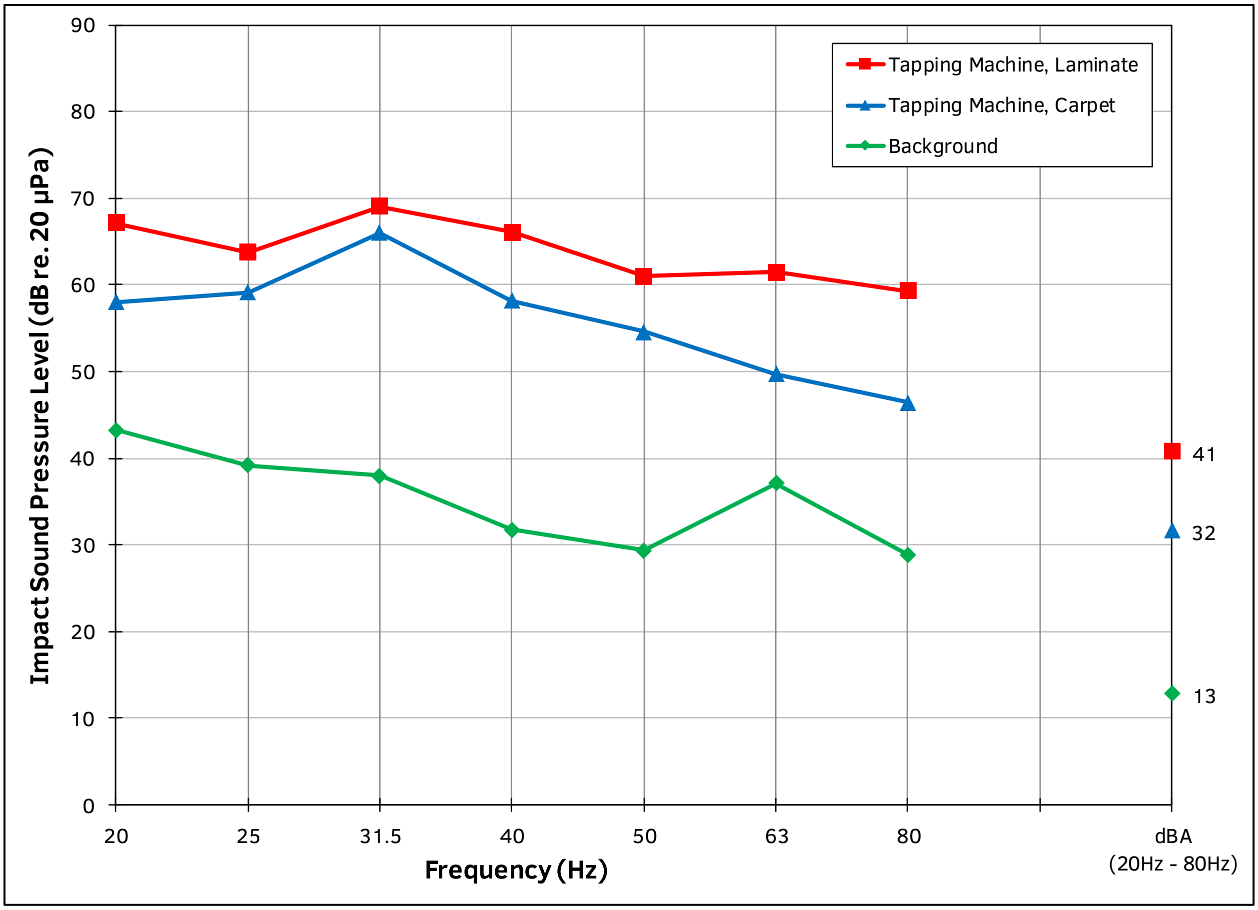

Figure 6 – Plot of measured tapping machine impact sound pressure levels.

We can draw the following conclusions from these results:

– For both the carpet and laminate finished floors, the tapping machine produced impact noise at the 20 Hz to 80 Hz frequencies that was more than 10 dB louder than the measured background noise levels.

– The tapping machine ISPLs do not trend well with the walker levels. For the carpet tests, the difference at each frequency ranges from -8 dB to +10 dB. The differences for the laminate floors are +3 dB to +18 dB.

– The tapping machine carpet and laminate results are not similar, with differences at the individual frequencies ranging from 3 dB to 13 dB. These results are not like the walker and ball drop tests that had similar results for both flooring finish types.

– The 20 Hz to 80 Hz overall A-weighted levels for the tapping machine carpet and laminate tests were 9 dBA apart, which is much more than the 2 dBA difference for the walker and ball drop tests.

Developing a Single Number Rating

If a single number rating for low-frequency impact sound insulation provided by floor/ceiling assemblies is to be widely accept in the USA, the tests should ideally be performed using a tapping machine per ASTM standard E1007. However, the tapping machine low-frequency ISPLs in the test results above did not correlate well with the walker results. The ball drop test results had better correlation with the walker results, but the ball drop ISPLs were louder than the walker ISPLs and did not trend exactly the same.

In an attempt to resolve these issues, we hypothesize that ISPLs from tapping machine and ball drop tests can be modified to resemble walker results by applying correction factors to the test data. Based on ISPL measurements in multiple buildings using walker, ball drop and tapping machine sources, we have developed a method for producing a low-frequency impact insulation single number rating for floor/ceiling assemblies. The method can be used on any floor/ceiling type, including concrete assemblies. Based on the standardized impact sound rating, or ISR, we have named this new single number rating the low-frequency impact sound rating, or LISR.

For familiarization and correlation purposes, our goal was to have the calculated single number LISR values scaled similar to typical field measured apparent impact insulation class, or AIIC, test ratings. Table 1 shows the typical range of AIIC / LISR ratings, how they relate to subjective perceptions of footfall noise (can vary by project type), and expected quantity of resident complaints.

Table 1 – AIIC / LISR Ratings Compared to Subjective Impressions

AIIC / LISR Rating	Subjective Impressions of Footfall Noise	Expected Complaints
Less than 40	Normal walking loud	Very many complaints
40 to 45	Normal walking clearly audible	Many complaints
45 to 50	Normal walking somewhat audible	Some complaints
50 to 55	Normal walking audible with fairly low background noise	Few complaints
55 to 60	Normal walking audible with very low background noise	Very few complaints
60 or higher	Normal walking largely inaudible	Virtually no complaints

The following lay out the process for determining the LISR rating:

1. Perform impact sound insulation tests of floor/ceiling assemblies.
2. Evaluate the measured ISPLs in one-third octave bands from 25 Hz to 80 Hz (i.e., $ISPL_{25}$, $ISPL_{31.5}$, $ISPL_{40}$, etc.).
3. Apply an A-weighting to each of the one-third octave band ISPLs (i.e., $ISPL_{A25}$, $ISPL_{A31.5}$, $ISPL_{A40}$, etc.) so that they correlate with human subjective hearing at the respective frequencies.

4. Evaluate the A-weighted impact sound pressure level at each whole octave band using equations (A) and (B).

(A) $$ISPL_{A31.5} = 10 * \log\left(10^{\frac{ISPL_{A25}}{10}} + 10^{\frac{ISPL_{A31.5}}{10}} + 10^{\frac{ISPL_{A40}}{10}}\right)$$

(B) $$ISPL_{A63} = 10 * \log\left(10^{\frac{ISPL_{A50}}{10}} + 10^{\frac{ISPL_{A63}}{10}} + 10^{\frac{ISPL_{A80}}{10}}\right)$$

5. Use equations (C) and (D) and the corresponding correction factors (CF) listed in Table 2 to determine the low-frequency impact sound rating at each octave band. Because the tapping machine results do not trend well with the walker results on varying floor finish types, separate tapping machine correction factors are listed for soft flooring surfaces (e.g., carpet, carpet and pad, rugs, etc.) and hard finished floors (e.g., tile, wood, laminate, vinyl, etc.).

Table 2 – LISR Impact Test Correction Factors

Impact Method	Correction Factors	
	$CF_{31.5}$	**CF_{63}**
Walker	70	70
Ball Drop	89.3	88.5
Tapping Machine - Hard Surface Flooring	77.8	86.4
Tapping Machine - Soft Surface Flooring	73.5	73.1

(C) $$LISR_{31.5} = CF_{31.5} - ISPL_{A31.5}$$

(D) $$LISR_{63} = CF_{63} - ISPL_{A63}$$

6. As with overall A-weighted sound pressure levels, the $LISR_{31.5}$ and $LISR_{63}$ results are summed so that similar levels reduce the overall rating and the lower of the two octave band ratings has the greatest effect on the overall rating. Equation (E) is used to calculate the final LISR rating.

(E) $$LISR = -10 * log\left[\left(10^{\frac{LISR_{31.5}}{10}}\right)^{-1} + \left(10^{\frac{LISR_{63}}{10}}\right)^{-1}\right]$$

Table 3 shows the LISR results for the walker, ball drop and tapping machine test results on each of the six tested floor/ceiling assemblies.

Table 3 – LISR Results for Each Tested Floor/Ceiling Assembly and Impact Source

Test No.	LISR for Each Impact Source Type		
	Walker	Ball Drop	Tapping Machine
Laminate Test #1	39	41	41
Laminate Test #2	43	42	42
Laminate Test #3	43	41	43
Carpet Test #1	43	43	42
Carpet Test #2	42	43	42
Carpet Test #3	44	43	41

We can draw the following conclusions from these results:

- All of the results have LISR ratings between 39 and 44. Our impression from the walker tests was that low-frequency impact noise was clearly audible. Based on the subjective impressions listed in Table 1 above for an LISR in the 40 to 45 range, the test results match this subjective impression.
- Without correction factors, the raw ball drop and tapping machine ISPL results would have produced LISR values that varied greatly from the walker tests, and the tapping machine results would have varied greatly by flooring type. With these corrections, all of the LISR results are near 45.
- The walker tests, which are expected to have lower reproducibility, had LISR results that varied by 5 points. The more highly reproducible ball drop and tapping machine test results only varied by 2 points across all six of the tests. This may mean that the ball drop and tapping machine tests have less variability than the walker test.

Table 4 shows how the measured LISR ratings from the tapping machine tests compare to the AIIC results for the same tests.

Table 4 – LISR and AIIC Results for Each Tested Floor/Ceiling Assembly

Test No.	Impact Sound Insulation Ratings	
	LISR	AIIC
Laminate Test #1	41	50
Laminate Test #2	42	48
Laminate Test #3	43	48
Carpet Test #1	42	74
Carpet Test #2	42	75
Carpet Test #3	41	73

As we expected, the AIIC ratings were near 50 for the laminate finished floors and 75 where carpet finished. However, as shown in Table 3, the walker LISR ratings were not 25 points apart, but rather within a few points of each other. If only the AIIC results are reviewed, it would be reasonable to expect residents to be very satisfied with the floor/ceiling assembly impact insulation where finished with carpet and pad. However, when reviewed in combination with the LISR results, it is apparent that residents may have as many complaints about footfall noise on the carpet finished floors as they may for floors finished with laminate.

Conclusions

Residents, building owners, architects and acoustic consultants are concerned about footfall noise transmission through floor/ceiling assemblies. While the standardized AIIC rating can be used to evaluate floor/ceiling impact insulation for mid- and high-frequency footfall noise, a separate rating system is needed to evaluate audible low-frequency impact noise that is ignored by the AIIC system. In this paper, we have reviewed floor/ceiling impact noise as produced by a walker, ball drops and a tapping machine. The ball drop source has reasonably good correlation with the walker source but is louder. The tapping machine also produces louder results than the walker source, but another disadvantage is that the results varied greatly with floor finish type.

A single number rating method is needed that evaluates low-frequency impact insulation of floor/ceiling assemblies with the following in mind:

- The impact noise source should produce reproducible results. Some source options may be a dropped ball or a standardized tapping machine.
- Tests using a tapping machine should be performed in accordance with ASTM standard E1007.
- The overall rating results should correlate well with tested results using a walker source.

ESI has developed a single number rating method called the low-frequency impact sound rating, or LISR, that uses these key aspects. While this seems to be a step in the right direction for creating a standardized rating method, more research and review by the acoustic community is necessary to evaluate the accuracy, efficacy and reproducibility of the method.

Future research could include:

- Review of LISR results using tested results by others.
- Have multiple agencies perform tests on the same floor/ceiling assembly samples to evaluate LISR reproducibility.
- Develop requirements for minimum measurement time and test position to accurately measure impact sound pressure levels down to the 25 Hz frequency.
- Evaluate how different soft flooring finishes (e.g., thick carpet, thin carpet, carpet and pad, rugs, etc.) affect the LISR results.