Optimizing floor-ceiling assemblies in wood-framed multifamily buildings using a two-rating method of evaluating impact isolation

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Abstract

In the United States of America (USA), Building Code regulations for airborne and impact sound insulation in multifamily residences are limited and do not extend to all locations and project types. Providing higher levels of sound isolation is driven largely by financial considerations, perceived marketplace and experience. Buildings with higher levels of impact isolation generally have higher construction costs, but also can demand higher rents or selling prices, and developers seek to optimize their designs to balance these constraints. The authors have worked with several large multifamily housing developers to develop separating floor-ceiling assembly designs. This is a cyclical process in which an assembly is designed, tested in the laboratory, built, tested in the field, evaluated with respect to occupant satisfaction; the assembly is then modified as necessary and the process repeats. To evaluate the assemblies in the field and relate to occupant satisfaction, the authors utilize a two-rating method of evaluating impact noise isolation, previously developed \([1,2]\). The two-rating method has proven more effective than the existing single number ratings for predicting occupant reaction, evaluating products, and providing guidance for future design improvements.

Keywords: impact testing, floor-ceiling, rating
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1 Introduction

In the United States of America (USA), building codes define only a minimum level of acoustical requirements (comparable approximately to Class F of the COST Action classifications [3]), or have no requirements at all. Therefore, little guidance is provided for residential builders who desire an improved level of acoustical performance for residents. In this paper we describe the process of designing and optimizing the floor-ceiling assembly for one multi-family housing developer. It is a cyclical process where occupant reaction provides feedback for continual modifications to the design.

In order to provide quantitative evaluations, a large number of field tests have been performed on the post-construction assemblies. The authors have previously developed a two-rating method for evaluating impact noise, which we used in developing and optimizing the design. This also serves as an example of the use of the two-rating method in real-world conditions.

2 Impact isolation rating methods

2.1 Building code requirements

In the USA, the building code requirement for field (in situ) testing of floor-ceiling assemblies between residential units is a minimum rating of NISR 45, where NISR is Normalized Impact Sound Rating [4]. NISR is similar to ISO rating $L'_{n,T,w}$ except that the rating scale is reversed so that higher ratings correspond to better performance (lower noise levels). The two ratings are approximately related by $L'_{n,T,w} = 110 – \text{NISR}$.

In floor framed with wood joists, such as the projects considered in this paper, thudding from footfalls at frequencies below 100 Hz is commonly considered problematic. The ISO has developed spectrum adaptation terms to attempt to quantify low-frequency impact noise, and the COST Action limits are defined in terms of $L'_{nT,50} = L'_{nT,w} + C_{50-2500}$. In North America there is no similar rating system, and frequencies below 100 Hz are not considered in impact noise regulation.

2.2 A two-rating method for evaluating impact isolation

Over the previous two decades the authors have worked to develop a two-rating method of evaluating impact noise, and we summarize our current findings here. The low-frequency rating to quantify thudding is based on the sound pressure level in the 50–80 Hz bands. The rating is called LIR for Low-frequency Impact Rating [2] and is defined so that higher ratings correspond to better isolation.
A new rating called HIR or High-frequency Impact Rating [1] has been developed, which is similar to the existing ratings except that the lower limit of the frequency range is 400 Hz. A separate rating for mid- and high-frequency impact noise does not seem to be necessary as this frequency range is covered by existing NISR or \( L'_{n,T,w} \) ratings. However, the authors have found that the high-frequency impact noise such as dropping objects, heel clicks, and dragging furniture, the existing ratings do not perform well in evaluating the acoustical performance. Often changes to the finish flooring or sound mats below floating floors causes a large change in the sound level due to these sources at frequencies 400 Hz and above, but only a small change to the rating reported. This occurs when the rating is controlled by noise in the 100–315 Hz bands, which generally does not change with changes in finish flooring or sound mats. Therefore, the HIR offers the ability to better evaluate the acoustical performance of all of the impact events that over a the high frequency range meaning a better evaluation of high frequency acoustical performance.

2.3 Classifications

In addition to the building code minimum, the International Code Council has published ICC-G2 Guidelines for Acoustics [5] which suggest two additional classifications, Acceptable and Preferred. Table 1 shows the COST Action ratings and the ICC-G2 suggestions. The \( L'_{n,T,50} \) ratings have been converted into approximate NISR ratings for ease of comparison, bearing in mind that NISR does not measure below 100 Hz.

Keeping the three classifications of the ICC-G2, the authors have tentatively defined classification limits for the LIR and HIR rating systems as shown in Table 1.

<table>
<thead>
<tr>
<th>COST Action TU0901</th>
<th>ICC-G2</th>
<th>Two-rating method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>( L'_{n,T,50} )</td>
<td>110- ( L'_{n,T,50} )</td>
</tr>
<tr>
<td>Class A</td>
<td>( \leq 44 )</td>
<td>( \geq 66 )</td>
</tr>
<tr>
<td>Class B</td>
<td>( \leq 48 )</td>
<td>( \geq 62 )</td>
</tr>
<tr>
<td>Class C</td>
<td>( \leq 52 )</td>
<td>( \geq 58 )</td>
</tr>
<tr>
<td>Class D</td>
<td>( \leq 56 )</td>
<td>( \geq 54 )</td>
</tr>
<tr>
<td>Class E</td>
<td>( \leq 60 )</td>
<td>( \geq 50 )</td>
</tr>
<tr>
<td>Class F</td>
<td>( \leq 64 )</td>
<td>( \geq 46 )</td>
</tr>
</tbody>
</table>

3 Assemblies and Testing Results

The assembly (shown in Figure 1) is framed with 2x10 (nominal inch dimensions, approximately 38 x 240 mm) solid wood joists with plywood subfloor sheathing and 90 mm (3.5 in.) batt insulation in the joist cavities. The floor side is finish floor over 25 mm (1 in.) gypsum concrete over 6 mm (1/4 in.) primary resilient sound matting. The ceiling side is one layer of 16 mm (5/8 in.) gypsum board on 12 mm (1/2 in.) resilient channels. Finish flooring was limited to carpet in bedrooms and most living rooms, but hard surface flooring was desired in the living rooms as well. Hard surface flooring in living areas was engineered wood laminate flooring, generally installed on top of a thin foam secondary resilient sound matting.
We have divided the testing program into 4 groups that define specific effort to improve assembly performance, which covered at least 16 projects and was spread out over 8 years. The first group (Group 1) was the original design. This assembly had been constructed for approximately 20 years in buildings. Group 2 involved settling on a design and preferred set of materials optimizing acoustical performance, cost and constructability. Group 3 included establishing a construction Quality Assurance program. By Group 4 the base assembly was well-established and investigations involved evaluating new products and construction methods, as well as increasing the number of rooms with hard surface flooring.

3.1 Original Assembly

The original assembly (Group 1) generated excessive complaints and was evaluated by the developer to be completely unacceptable based on their subjective impression and the reaction of the building occupants. Prior to our involvement, a variety of improvements were attempted based marketplace knowledge of products available. These efforts were not coordinated well and did not examine the ability of the contractor to build the original floor ceiling reliably and in a consistent manner. Quality Control training and expectations had not been completed at this stage so, to certain extent, the ability to predict the performance benefit provided by any modifications was moot as the original assembly (Group 1) had not been reliably and consistently constructed. Some of these attempts improved the assembly, were considered as part of coordinated design improvement, but were not adopted for reasons associated with production, cost or material supply chain limitations.

The test results of the original assembly (Group 1) using the two-rating method are shown in Figure 2. The suggested boundaries of Preferred and Acceptable ratings as listed in Table 1 are also shown. The average single-number ratings are listed in Table 2.

Note that while the single-number ratings do not indicate excessively poor performance, plotting the data on two axes makes it obvious that the assemblies were insufficient. In the single rating system, the average performance of the assembly met minimum Building Code requirements, but...
in dual rating system it could clearly be seen as unacceptable, which was consistent with the subjective reaction.

Figure 2: Original assembly. Blue circles shown the original assembly (Group 1), red squares included some of the Client’s attempts to improve the assembly.

Table 2: Average Single-Number Impact Ratings

<table>
<thead>
<tr>
<th>Condition</th>
<th>n</th>
<th>NISR</th>
<th>L'_{nt,50}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>40</td>
<td>51.9</td>
<td>5.2</td>
</tr>
<tr>
<td>Client Attempts</td>
<td>22</td>
<td>57.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Group 2</td>
<td>33</td>
<td>55.5</td>
<td>5.6</td>
</tr>
<tr>
<td>Group 3</td>
<td>51</td>
<td>59.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Group 4</td>
<td>18</td>
<td>59.8</td>
<td>2.6</td>
</tr>
</tbody>
</table>

3.2 Group 2

Group 2 was focused on defining a base assembly. The various attempts that had been tried were evaluated, and the cost-benefit ratio was analysed. There were additional complications due to
fire rating requirements, supply chain constraints and production construction that had to be considered.

Some of this investigation was documented in an earlier conference paper [6]. It was determined that using resilient clips that contained neoprene isolation elements did not provide enough benefit compared to the specified resilient channel to justify the additional cost. However, damped drywall products (gypsum board panels made of thinner layers laminated with viscoelastic glue) when installed on resilient channel showed significant benefit. In order to satisfy both fire and acoustical requirements, a custom thickness of damped drywall had to be commissioned, tested, and listed with regulatory agencies, a process that took almost 3 years.

The difference between the Group 2 assembly and the original is that damped drywall was used at hard surface locations, and regular gypsum board was used at carpeted locations. Field testing verification was performed, and the results are shown in Figure 3.

Note that although some of the early attempts achieved better acoustical performance (compare Figure 3 with red in Figure 2), the early attempts were made haphazardly and without regard for fire, cost, or constructability. The assemblies tested in Figure 3 are uniform, coordinated assemblies with well-defined costs, material availability and production schedules taken into account.

Note that the single number ratings (Table 2) improved only a few points, and the $L'_{nT,50}$ was unchanged. However the occupant reaction was improved, and the client’s evaluation was that the improvement was sufficient to allow installation of hard surfaced flooring in all rooms except bedrooms. The two-rating method (Figure 3) shows that the improvement was mostly in the high-frequency metric.

![Figure 3: Group 2 testing (green), with original assembly tests shown greyed-out.](image)
3.3 Group 3

It was discovered, however, that errors had been made during construction and the consistency and quality of the installation of materials could be improved. A different, lower-performing resilient channel had been installed on some buildings, and there were also errors in installation. Some of these errors account for the lower-performing tests in Round 2 (the cluster of points to the left in Figure 3).

A Quality Assurance program was started, which involved construction jobsite observations of the construction of the assemblies. While observations had been performed on previous projects, the visits became more regular and included a much larger percentage of the homes. These projects with the Quality Assurance program constitute Group 3; field test results are shown in Figure 4.

The average single-number ratings improved 3–4 points, due to eliminating the floors that were lower-performing due to construction issues. However the subjective improvement was greater than a few points in rating would indicate. Comparison of Figures 2 and 3 shows that the improvement was in both axes.

![Figure 4: Group 3 testing (purple), with earlier assembly tests shown greyed-out.](image)

3.4 Group 4

This is the current state of the assembly. Several tests from current projects are shown in Figure 5. Although the numerical average is unchanged, the number of lower-performing tests is
continuing to be reduced. There is an increased percentage of hard surfaced floors in these projects, which may demand higher performance. There is continuous interest in modifying the design to allow for less expensive materials while maintaining the acoustical performance. The cycle of design continues.

Figure 5: Group 4 testing (orange), with earlier assembly tests shown greyed-out.

4 Comparison of Single Number and Dual Number Ratings

The results of the above study are summarized in Table 3.

<table>
<thead>
<tr>
<th>Condition</th>
<th>NISR</th>
<th>LIR</th>
<th>HIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>51.9</td>
<td>44.5</td>
<td>56.1</td>
</tr>
<tr>
<td>Client Attempts</td>
<td>57.4</td>
<td>50.2</td>
<td>66.0</td>
</tr>
<tr>
<td>Group 2</td>
<td>55.5</td>
<td>45.8</td>
<td>65.5</td>
</tr>
<tr>
<td>Group 3</td>
<td>59.7</td>
<td>50.4</td>
<td>68.1</td>
</tr>
<tr>
<td>Group 4</td>
<td>59.8</td>
<td>50.7</td>
<td>68.6</td>
</tr>
</tbody>
</table>

The two number rating is a better evaluation of subjective reaction. Based on the average NISR rating of the original assembly, one would not expect a large number of complaints; this did not
correlate with the reaction. Looking at the scatter plot in the two-rating system makes it clear that the floors are insufficient.

From the original floors to the current, Table 2 shows about an 8 point improvement in NISR and just a 4 point improvement in $L'_{NT,50}$. The improvement in terms of the subjective reaction of the occupants has been far greater than this change (a single class in the COST Action) would indicate. The average LIR improved by 6 points and the HIR improved by 12 points. Examination of the two rating numbers, especially in the form of a scatter plot, makes evaluating the performance easier and more accurate and provides more information than the single number ratings. Attempting to collapse both axes into a single number results in the loss of a significant amount of useful information, which is critical in defining how and where to modify and manage acoustical performance.

The $L'_{NT,50}$ metric is intended to include the low-frequency information within the rating. However, a single rating, no matter how constructed, cannot adequately express variation with two degrees of freedom. The single number rating is often controlled by the low or high frequency levels separately, and hence becomes “fixed” and unable to show variation along the other axis. In this case, the $L'_{NT,50}$ is controlled by low frequency noise (and therefore almost perfectly correlated with LIR), while the larger improvement in high-frequency isolation remains hidden and obscured. Using two metrics not only demonstrates both behaviors, but suggests avenues for future improvements. We might determine that a higher HIR is desired, improve (for example) the sound mat beneath the finish floor, improving the HIR but leaving the $L'_{NT,50}$ rating unchanged. The single rating does not evaluate, suggest, or justify the change, while the two rating system has the ability to better pinpoint and analyzed potential deficiencies.

For this client and their target occupants, the high frequency performance is more important than the low frequencies. The data suggests there may be reason to adjust the boundaries of the Acceptable and Preferred zones, or possibly add another region.

5 Conclusions

This paper has demonstrated by example the iterative process by which clients arrive at acoustical design criteria suitable for their projects. Because of the lack of regulation in the USA, this procedure is left up to the individual builders. Unfortunately there are relatively few builders who have the interest and resources to go through this process. These builders tend to arrive at decisions by trial and error, but never take into account the need to understand how their assembly is constructed and managing the process so there is a clear understanding of what is constructed. Those that do, however, can arrive at criteria that are tailored to their project type, preferred construction, and clientele. These decisions are conducted in a manner such that the resultant acoustical performance is clearly understood because all portions are managed. This is a new paradigm in the means of generating assemblies that meet (but do not exceed) the needs of the client.

The example also demonstrates the benefit of a two-rating method for evaluating impact isolation. The difference between the unacceptable and satisfactory assemblies is significantly larger with the two ratings. The two rating system is better correlated with occupant reactions, and can
suggest avenues for further design improvements, both of which can be masked when using a single-number rating.

Acknowledgments

The authors thank the employees of Veneklasen Associates and Western Electro-Acoustic Laboratory for their continued support.

References


