ICSV14
Cairns • Australia
9-12 July, 2007

14th International Congress on Sound & Vibration

LIGHTWEIGHT TIMBER FLOORS: A SIMPLE GUIDE TO LOW-FREQUENCY IMPACT INSULATION.

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Abstract

One of the major problems with the impact insulation of lightweight floors is poor insulation of low-frequency impact sounds. This problem is often expressed by occupants as audible 'thud' and 'boom' noises. A recent Australasian project looked at ways to improve the low-frequency impact insulation of timber floors. The particular emphasis was to produce floor designs which can be easily built in New Zealand and Australia. It is a difficult problem with many confounding factors involved. The project produced a number of theoretical and experimental results. In this paper we look at the translation of these results into design recommendations which hopefully can be used directly by building designers.

1. INTRODUCTION

Lightweight inter-tenancy floors tend to be regarded as having poor acoustic performance. This poor performance is often expressed by occupiers as the hearing of 'bumps and thumps' from above, and is due to poor low-frequency impact insulation. These low-frequency impact sounds are mostly caused by people moving around on the floor above. Another contribution to these low-frequency impact sounds can be things such as doors closing or heavy objects being dropped onto the floor. On the other hand, experience shows that heavy masonry or concrete floor systems perform more acceptably in this area of low-frequency impact sound insulation.

Something which confounds the problem of low-frequency sound insulation is that it is often difficult to measure and rate. It can be difficult to measure and predict low-frequency performance due to the fact that the rooms abutting the building element being considered have a significant influence on the sound transmission through the building element, while being difficult to factor out. It can also be difficult to rate the low-frequency performance of a floor because we don't really understand how objective measurements relate to people's perceptions of the low-frequency impact insulation of a floor.

1.1 Researching the problem and developing solutions.

A team of Australasian building acoustics researchers, companies and associations (Scion, The University of Auckland, Prendos Ltd., NZPMA, CSR, Gib, CHH, Tenon) formed a consortium to tackle this problem, with part funding from the FWPRDC. The members of the team consisted of acoustic professionals and researchers, mathematicians, construction experts, structural engineers, and people expert in the area of bringing new construction ideas and techniques to the market place.

The research into this problem essentially progressed existing research on the topic with the aim of producing floor/ceiling system design recommendations for timber floors having improved low-frequency impact sound insulation. The research itself combined theoretical and experimental analysis with subjective testing to achieve the aim.

Results of the research have been published in a number of papers [3],[4],[5], as well as in the overall research report [1]. However, what was really needed was a way to distil the results and then present the results to designers and engineers so that it can be easily used.

It was thought that a good way to communicate to design engineers would be through a points system, where certain aspects of a potential floor design are given points based on quantitative measures or qualitative features of their components. The resulting points are then added to give an overall total for the floor design. This can be compared to floors which have known overall low-frequency performance measures.

Subjective testing indicated that the loudness of low-frequency impact sounds was related to the subjectively perceived low-frequency performance of the floor [2]. As a result of these subjective results, the points system used to rate the low-frequency performance of a floor was based on the sound level produced by a 75kg male walker in soft shoes. To ensure only low-frequency sound was considered only frequencies below 200Hz were included. The quantitative values for the points used were based on a combination of theoretical results and experimental results of the research.

The results of the research only considered the element itself, and flanking sound was suppressed, hence the guide and the points system don't consider flanking transmission.

What follows in the rest of this paper is the essential content of the guide.

2. A GUIDE TO IMPROVING THE LOW-FREQUENCY PERFORMANCE OF TIMBER-JOIST FLOORS.

Consider the 'basic' inter-tenancy floor illustrated in Figure 1. It has (from tapping machine measurements) high-frequency impact sound insulation ratings of $L_{n,w} = 61$ dB and $L_{n,w} + C_I = 60$ dB, which are quite good for bare floor. However, the low-frequency impact sound performance is not very good, such that low-frequency footstep sounds can often be heard and identified.

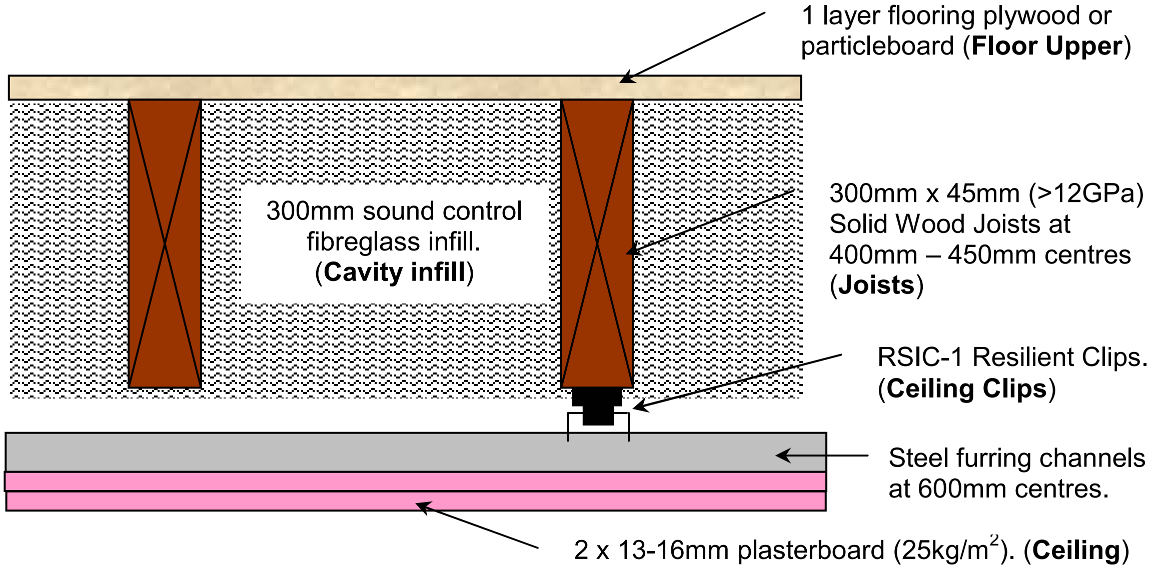

Figure 1. The 'basic' inter-tenancy floor.

2.1 Changes to the basic floor to improve low-frequency performance.

The following table summarises the changes that can be made to the basic floor in order to change its low-frequency impact insulation performance. The floor is divided into a number of parts, and the properties of each part which affect low-frequency impact sound are considered.

For each important part/property combination we consider a number of values the property could take, the affect this would have on the low-frequency performance and an example for each property value.

The effects changes have on a floor are given in terms of 'low-frequency impact sound level point' changes, which are added together to produce an overall low-frequency performance change. The points are related to the sound levels experienced in the room below the floor, and so a negative change is better.

To put this low-frequency point system in context, we can consider what we need to do to the basic timber-joist floor illustrated above to make its low-frequency performance similar to a concrete slab. Comparative measurements on timber and concrete floors show that to improve the basic floor so that its low-frequency performance is similar to a 150mm dense concrete slab floor, we need to reduce the low-frequency impact level by 10 points. Changing the 'low-frequency impact level points' by 3 points or more should produce noticeable performance improvements.

2.2 Table of low-frequency impact sound insulation improvement options.

(Yellow highlighted options are the 'basic' floor)

<table>
<tr><th>Part and Property Change</th><th>Value of property</th><th>Low-frequency impact sound level change</th><th>Example</th></tr>
<tr><td rowspan="5">Mass of floor upper surface and joists.
(Assumes joists are 20kg/m^2)</td><td>30 kg/m^2</td><td>0 points</td><td>1 layer of 20mm particleboard</td></tr>
<tr><td>40 kg/m^2</td><td>–2 points</td><td>2 layers of 20mm particleboard</td></tr>
<tr><td>60 kg/m^2</td><td>–4 points</td><td>27mm gypsum fibreboard on particleboard</td></tr>
<tr><td>100 kg/m^2</td><td>–6 points</td><td>35mm gypsum concrete on particleboard</td></tr>
<tr><td>140 kg/m^2</td><td>–7 points</td><td>50mm dense concrete on particleboard</td></tr>
<tr><td rowspan="4">Mass of ceiling
(Assumes ceiling is resiliently connected to joists)</td><td>12 kg/m^2</td><td>+2 points</td><td>1 layer of 16mm fire-rated plasterboard</td></tr>
<tr><td>25 kg/m^2</td><td>0 points</td><td>2 layers of 16mm fire-rated plasterboard</td></tr>
<tr><td>37 kg/m^2</td><td>–2 points</td><td>3 layers of 16mm fire-rated plasterboard</td></tr>
<tr><td>50 kg/m^2</td><td>–3 points</td><td>4 layers of 16mm fire-rated plasterboard</td></tr>
<tr><td rowspan="3">Stiffness of resilient ceiling connections
(Assumes 25 kg/m^2 ceiling and 300-400mm ceiling cavity depth)</td><td>0</td><td>–3 points</td><td>Independent ceiling joists with excellent low-frequency flanking vibration isolation (e.g. resiliently mounted on concrete walls) [Note 1]</td></tr>
<tr><td>450,000 N/m/m^2</td><td>0 points</td><td>RSIC-1 rubber clips (2 clips per m^2)</td></tr>
<tr><td>900,000 N/m/m^2</td><td>+2 points</td><td>Steel ceiling clips with resilient furring channels (e.g. GIB Rondo ceiling batten with GIB Rondo 311 clip)</td></tr>
<tr><td rowspan="2">Vibration Damping of upper surface</td><td>Little damping</td><td>0 points</td><td>Particleboard, gypsum concrete</td></tr>
<tr><td>A lot of damping</td><td>–2 points</td><td>60mm or more of granular infill (e.g. sand)</td></tr>
<tr><td rowspan="2">Connection of mass topping</td><td>Laid directly on subfloor</td><td>0 points</td><td>Concrete screed poured directly on to particleboard</td></tr>
<tr><td>Floating on resilient layer</td><td>–2 points</td><td>Concrete screed poured on to 10mm polyethylene foam underlay.</td></tr>
<tr><td rowspan="2">Vibration damping of ceiling clips</td><td>Little damping</td><td>+1 point</td><td>Steel ceiling clips</td></tr>
<tr><td>Some damping</td><td>0 points</td><td>RSIC-1 rubber clips</td></tr>
<tr><td rowspan="3">Cavity total sound absorption
(assumes use of RSIC-1 clips). [Note 2]</td><td>500 Rayls</td><td>0 points</td><td>100mm fibreglass batts or blanket</td></tr>
<tr><td>1500 Rayls</td><td>0 points</td><td>300mm fibreglass batts or blanket</td></tr>
<tr><td>3000 Rayls</td><td>–1 point</td><td>300mm rockwool</td></tr>
<tr><td rowspan="2">Cavity depth
(assumes use of RSIC-1 clips). [Note 3]</td><td>200 – 300mm</td><td>+1 point</td><td></td></tr>
<tr><td>300mm or more</td><td>0 points</td><td></td></tr>
</table>

Notes:

1) It is important to ensure that vibration from the floor does not travel along the ceiling joists. It can be difficult to control this low-frequency flanking in an all-timber construction. It is possible, however, to stop vibrations entering the ceiling joists by resiliently mounting the floor and ceiling joist ends on a concrete wall, ensuring that there is no timber connecting the ceiling joists to the floor joists.

2) Since most of the vibration is carried through the clips, changing the sound absorption in the cavity doesn't change the performance greatly. If however, separate ceiling joists are used, increasing the sound absorption is more beneficial.

3) As for note 2, a large cavity depth is not greatly beneficial due to the stiffness of the ceiling clips.

One can use the above table to design a timber floor, and get an idea of its low-frequency impact sound performance. Once the floor features have been determined, the joists can be selected to suit the mass and span of the floor. Joist stiffness does not greatly affect the acoustic performance of the floor. In fact, research has shown that less stiff floors can be beneficial for low-frequency impact insulation. Therefore it is recommended that a minimum joist stiffness be used, given the constraints of adequate structural and felt vibration performance. (A fundamental resonance greater than 8Hz is often required to minimise felt vibration problems).

It must be noted that the dimensions of the receiving room can significantly influence the low-frequency acoustic performance of a floor. If the resonant frequencies of the floor match the resonant frequencies of the receiving room then the acoustic insulation performance can be impaired. Similarly, if no resonances match then the performance can be better than expected. Fortunately in timber constructions, resonances are more highly damped and structural resonances more closely spaced than concrete buildings resulting in less severe performance changes caused by different room dimensions.

2.3 Low-frequency impact sound level points

The rating of low-frequency impact sound using 'low-frequency impact sound level points' comes from subjective research into annoyance of impact sounds. It was found that the loudness of the sounds was closely related to annoyance. The 'low-frequency impact sound level points' are therefore closely related to the $L_{A,Eq}$ sound levels in dB produced by 80 kg male footsteps in soft-soled shoes when filtered to removed any frequency components above 200Hz. We find that such footsteps on the 'basic floor' produce sound levels of $L_{A,Eq}$ = 35 dB in a 'standard' room below, and the same footsteps on a 150mm concrete slab floor produce sound levels of $L_{A,Eq}$ = 26 dB.

2.4 High-frequency impact insulation performance.

When designing the floor for improved low-frequency acoustic performance, consideration also needs to be given to high-frequency performance requirements. There are some low-frequency improvement options which have worse high-frequency performance compared to other options. An example is adding mass to the upper surface. One option is to pour a concrete screed on the subfloor. A concrete screed will improve the low-frequency impact insulation, but the hard surface will result in more high-frequency sound being transmitted. If the use of hard wearing surfaces such as ceramic tiles is desired then such a screed needs to be floated on a resilient layer, or a resilient layer added under the tiles. Another option is to use a granular material such as sand on the subfloor, which is then covered by a wearing surface. This has the advantage of adding mass while also improving the high-frequency insulation performance.

This document is not intended to cover the issue of high-frequency impact insulation, and the reader is referred to the extensive literature and expertise which cover the problem much more fully.

3. EXAMPLES OF TIMBER FLOORS WITH IMPROVED LOW-FREQUENCY IMPACT INSULATION PERFORMANCE.

The following examples illustrate how the table can be used to assess the low-frequency impact sound insulation performance of some timber-joist floors with improved low-frequency performance.

3.1 Floating gypsum concrete screed floor.

Start with the 'basic' floor of Figure 1. We add 30mm of gypsum concrete floating on 12mm of polyethylene foam.The joists were 300mm deep I-beams at 450mm centres, spanning 5500mm. This floor is shown in Figure 2. According to our table of low-frequency improvement options, we get a reduction in low-frequency, footstep-type sound of 6 points for the gypsum concrete mass, 2 points for floating the gypsum concrete. This adds to a reduction of 8 points, making it similar to a 150mm concrete floor. Experimental measurements showed that the footstep sound level below 200Hz was $L_{A,Eq} = 24$ dB, compared to a concrete slab at $L_{A,Eq} = 26$ dB, and compared to the basic floor at $L_{A,Eq} = 35$ dB. All sound level comparisons are for a receiving room 5.5m long by 3.2m wide by 2.4m high with plasterboard lining (i.e. an average low-frequency absorption coefficient of 0.15). High frequency impact insulation performance measured in accordance with ISO 140-6 and calculated in accordance with ISO 717-2 was $L_{n,w}$ (C_I) = 52 (-2) dB.

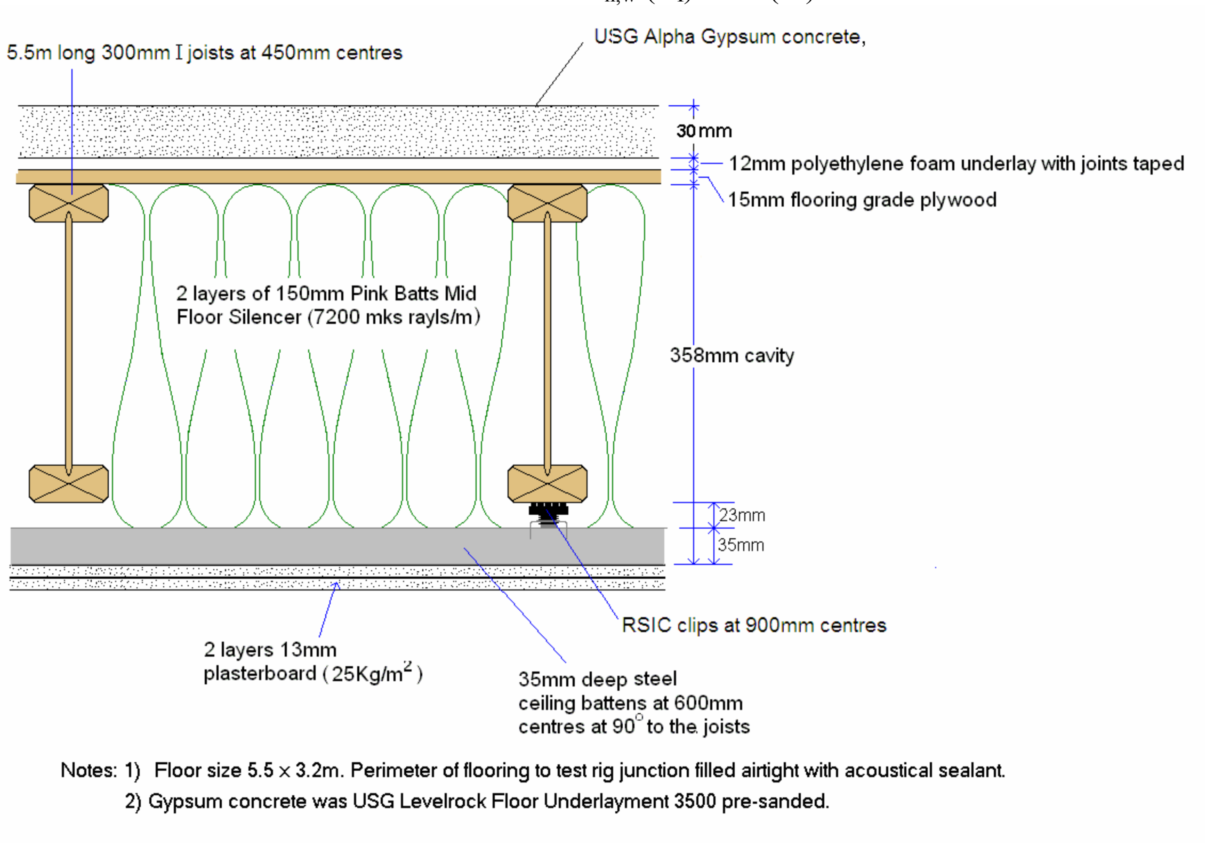

Figure 2. Example floor with floating gypsum concrete screed.

3.2 Heavy sand/sawdust-filled floor.

Start with the 'basic' floor of Figure 1. 90mm deep battens at 450mm centres screwed or nailed to the floor. The resulting cavity was infilled with 85mm of a paving sand and sawdust mix (80/20 ratio by volume), and topped with a plywood wearing surface. The mass of the floor upper (including joists) was 125 kg/m^2. The purpose of the sawdust is to improve the vibration damping of the sand. This floor is shown in Figure 3. According to our table of low-frequency improvement options, we get a reduction in low-frequency, footstep-type sound of 7 points for the upper floor mass, and 2 points for highly-damped granular infill. This adds to a reduction of 9 points, making it similar to a 150mm concrete floor. Experimental measurements showed that the footstep sound level below 200Hz was $L_{A,Eq} = 24$ dB. Subjective evaluation of this floor for low-frequency impact sounds showed that its low-frequency impact insulation performance compared well to a 150mm concrete floor. High frequency impact insulation performance measured in accordance with ISO 140-6 was $L_{n,w}$ (C_I) = 48 (-2) dB.

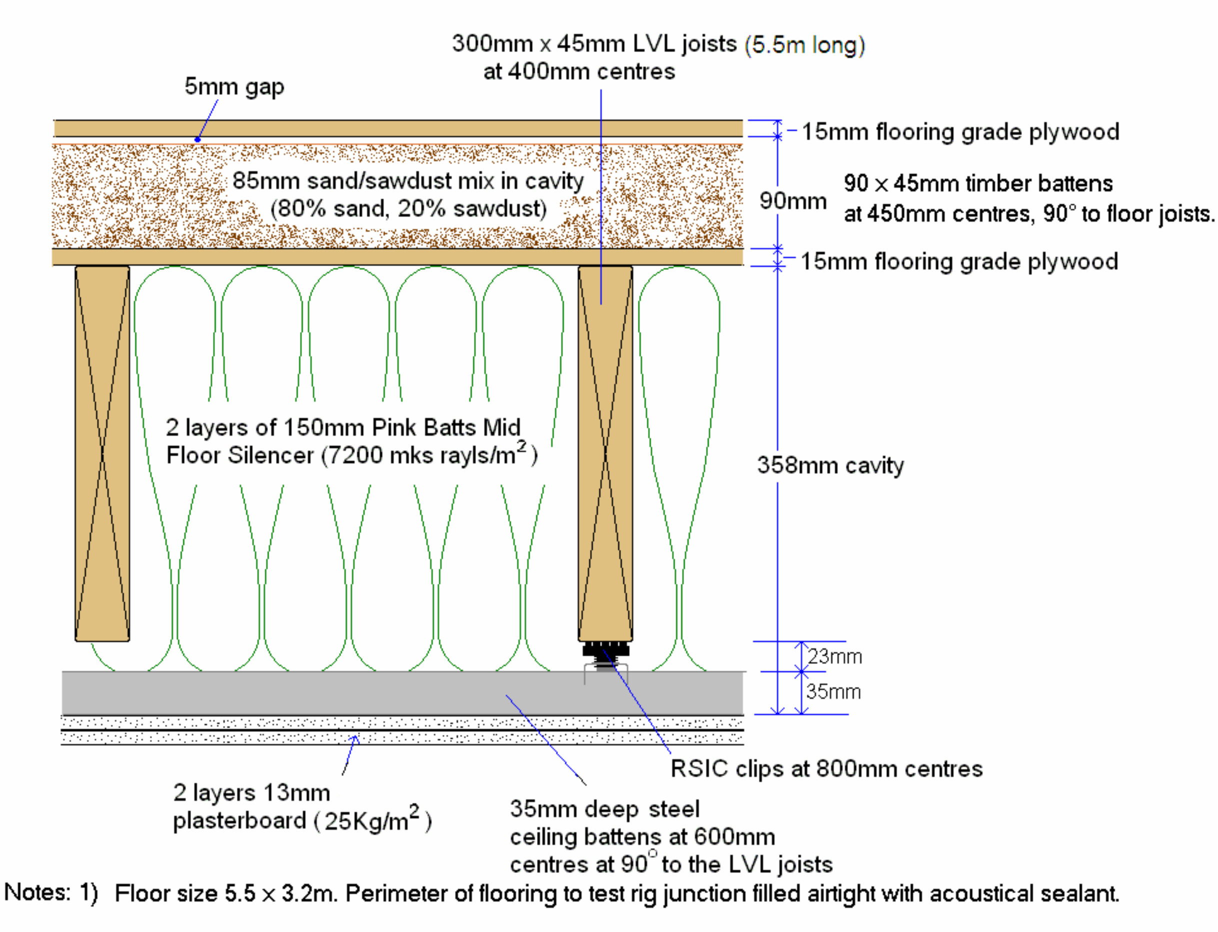

Figure 3. Example floor with deep sand/sawdust topping.

CONCLUSION

Low-frequency impact sound is an important factor to consider when designing timber-joist floors, particularly for inter-tenancy applications. Low-frequency sound is also a difficult thing to measure and predict, in part due to the complicated way rooms interact with the sound. Nevertheless, it is possible to improve the performance of such floors.

This paper provides a simple methodology to assess, in an approximate qualitative way, how a floor design will perform in terms of its low-frequency impact sound insulation.

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