Findings from Listening to Impacts on Floors

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Abstract

Subjective evaluations have been carried out to determine whether timber-based, inter-tenancy floor/ ceiling systems can be produced – using existing industry skills and techniques – which are as subjectively satisfactory as concrete slab based floors

Listeners' choices made during controlled A/B comparisons indicated that loudness – suitably extended to include the infrasonic frequency range – is better than standard metrics for ranking floors for their impact insulation.

However, since the ranking changed with the type of impact, a simple, single-figure performance description may not be adequate for indicating the overall performance as required in building specifications or building codes.

Introduction

The current perception of timber inter-tenancy floor-ceiling systems is that they don't perform acoustically as well as heavy masonry building systems particularly in terms of impact sound transmission from the floor above and this is seen as being predominantly a problem of poor insulation at low frequencies. A consortium of New Zealand building acoustics researchers and Australasian industries was set up to research the problem and produce light timber floor-ceiling system designs which would be comparable with concrete floor constructions and meet the acoustic requirements of the Australian and N Z Building Codes. In addition the brief required that these should be cost effective and buildable using existing construction industry skills.

Figure 1: Floor-ceiling test rig (top) side-view, (middle) top view with no floor, (bottom) top view with a floor under construction.

The project was conceived to be a comprehensive attack on the problem and combined theoretical modelling [1], experimental testing [2] and subjective evaluations.

Here we report the work and conclusions from the initial stage of subjective evaluations.

Our main target was to verify that light timber floor-ceiling designs are possible which can perform at least as well as a typical concrete floor construction, and for this purpose the reference concrete construction was taken as being a 150mm thick slab with a suspended plasterboard ceiling underneath.

Proof of success in meeting this goal would be that subjective evaluations of solution floors would show equal acceptance of these and the reference concrete construction or - even better - they would show our solution floors to be preferred.

These subjective evaluations should cover the full range of types of impacts expected in normal use of floors and they should be carried out under as realistic conditions as possible.

Also it would be preferable if the subjects making the evaluations could switch rapidly between the floor types to enable instant A/B comparisons.

So we carried out listening tests in a specially constructed Listening Room and designed the reproduction system to let the

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subjects receive the sounds as if they were living underneath the floor/ ceiling structures.

Recording the Sounds

The recordings of the impact sounds from the sample timber floors were made at the same time as the formal testing of the 26 floor-ceiling systems in a special purpose ceiling test rig (Fig. 1).

These were made with 4 microphones in the near field of the ceiling (70 mm away from the surface of the ceiling) and the microphones were positioned along a diagonal of the test floor.

The intention of making near field recording was to eliminate as far as possible the acoustics of the test rig chamber from the recordings (we also suppressed the chamber reverberation by means of a floor lining of thick sound absorber) and to be able to more accurately reproduce position and movement of the impact sources.

The actual impact sources we recorded included;

1. the standard tapping machine,
2. heavy tyre drops at 4 positions along a diagonal (this was equivalent to the Japanese Bang machine),
3. a 72 kg male walking along the diagonal,
4. the same male running along the diagonal,
5. Japanese Standard impact ball drops at the 4 diagonal positions, and
6. cutlery (spoon) drops from bench-top height (1.2m) at the 4 positions

Listening Room

The listening room (Fig. 2) was designed to meet the specifications

Figure 2: The special Listening Room for the subjective evaluations

of the IEC standard 268 part 13 for special Listening Rooms and also furnished to look and feel like a domestic environment.

The reason for doing this was that we wanted our subjects to have a sense of being in a domestic situation, as this is the most critical environment for acoustic privacy.

Because our homes are where we expect to be at our most private, the insulation required is not simply what will be sufficient to provide for short-term tolerance of sounds or what will give freedom from interruption of a defined activity (e.g. watching TV) but what is needed to satisfy our particular need for acoustic privacy.

In the limit we may define acoustic privacy as the state whereby no information about you or your neighbours (including both your and their presence) is communicated by sound. However, we may expect that, as with other human characteristics – such as hearing acuity – the need for acoustic privacy will vary with the individual.

Our knowledge of the form and extent of the distribution of this need in our population is, at this stage, rather limited but we have included questionnaires as part of the profiling of our subjects developed specifically for quantifying each subject's need for acoustic privacy and their intrinsic sensitivity to noise.

Note that noise sensitivity is quite distinct from hearing acuity – although hearing acuity may be a mediating factor. We may define noise sensitivity (NS) as "a persons inclination/tendency to be distracted by sound/noise".

IEC standard 268-13 [3] prescribes room size, room proportions and limits for the RT characteristic, all of which we comply with.

The reproduction system at the stage

of this initial project comprised a 4.2 system with the 4 loudspeakers concealed within the ceiling to provide directional realism for the impact sounds.

The design goal for the system was that it should provide a flat frequency response (+/- 3dB) in 1/3 octaves down to 10 Hz so that feel-able vibrations induced by the floors in the infra-sonic range would also be recreated. In the event we did not quite achieve this but we have met the criterion down to the 16 Hz 1/3 octave (Fig. 3).

In the continuation of the study which is currently underway we have managed to extend the response by the addition of a special sub-woofer down to 10 Hz and with a **tighter** equalisation overall.

The individual ceiling loudspeakers were fed 1 channel each of the 4 channel recordings and the 2 sub-woofers were fed an average mix of the low frequencies from the 4 microphones.

The sound levels at the listener position were the impact sound levels measured according to ISO 140 but adjusted to account for the RT difference between the test rig chamber and the listening room.

In order to have a test duration which was reasonable for subjects (typically it required 1 –1½ hours) we reduced the test excitations to 4 impact types on only 8 floors - the impacts being:

- the standard tapping machine at a central floor position
- walking on the bare floor
- walking on carpeted floor
- light impact ball drops at the 4 diagonal positions

The 8 test floors used in the evaluations are shown in Table 1.

Each test floor was paired with recordings made in a similar manner from the concrete reference floor so each pair of sounds contained the reference floor and one of the test floors but the impact type was always the same for each of the pair. Subjects were given no information about the floor constructions.

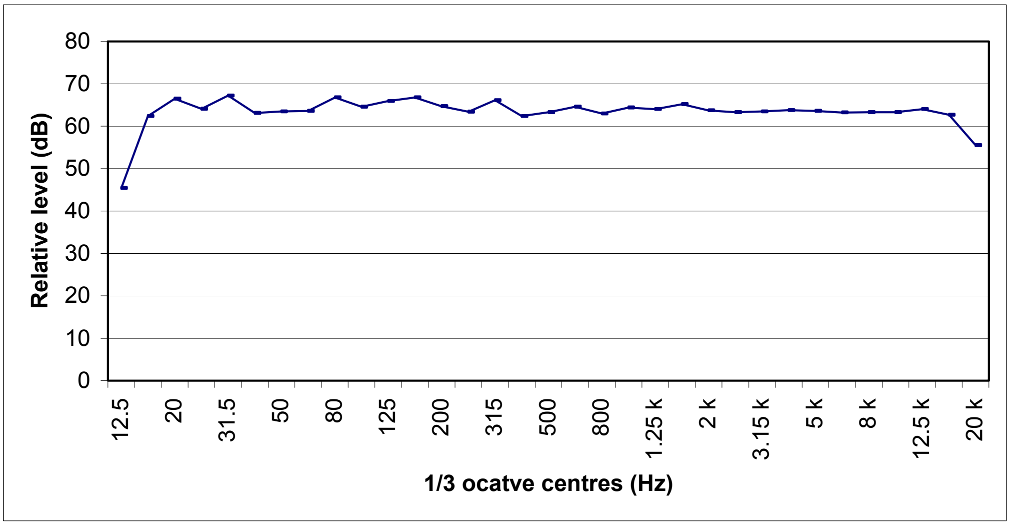

Figure 3: The frequency response of the reproduction system at the subject's position in the Listening Room.

The Subjects' Task

The subjects were asked to imagine they were going to have to live in an apartment but they were being given the opportunity to choose the type of floor-ceiling construction which

Floor Number	Description[1]	Joist Type
Reference	Concrete slab 150mm thick with ceiling + 65mm fibreglass	
2	1x16mm Plywood (i.e. basic floor) (7mx3.2m)	300 LVL @400c/s
3	Gib Sound Barrier system (7mx3.2m)	300 LVL @400c/s
8	45mm battens with 40mm sand/sawdust mix (5.5mx3.2m)	300 LVL @400c/s
9	90mm battens with 40mm sand/sawdust mix (5.5mx3.2m)	300 LVL @400c/s
14	Basic floor with transverse stiffening (5.5mx3.2m)	300 LVL @400c/s
18	1x16mm Plywood (i.e. basic floor) (5.5mx3.2m)	400 I-beams @ 600c/s
19	As 18 but with 4x13mm Noiseline to ceiling (5.5mx3.2m)	400 I-beams @ 600c/s
20	Transverse stiffening + Hebel floor (5.5mx3.2m)	300 I-beams @ 400c/s

Note: 1. All constructions include a suspended ceiling (except where stated otherwise) consisting of 2 layers Noiseline Gib (Gypsum board) mounted on Gib Rondo 35mm steel battens and resilient clips type RSIC.

Table 1: The floors used in the subjective comparison tests

would separate them from the apartment above. The choice would be from a range of constructions presented in pairs.

In response to each presented pair, our subjects answered 2 questions. The first simply asked which of the floors they would prefer to live under – this was a forced choice and they were not allowed a tie.

In the second they were asked to indicate the strength of their preference by making a mark on a continuous, semantic-differential scale (See Appendix 2 for the Questions and response sheet).

Results and Analysis

We used both the percentage preference scores and the relative strengths of the subjective differences to rank order the floors in terms of their performance for the different impacts (Table 2—refer next page).

Only rankings for the most critical situations:- heavy impacts (Japanese ball drop), hard/light impacts (i.e. tapping machine) and walking are given here. These show — perhaps not surprisingly — that there is a reversal of the preferred type of floor construction when the source changes from a soft-body, heavy impact to a hard, light impact.

The concrete floor is preferred when it is a heavy impact excitation with the Ball drop, but the timber constructions is preferred for impacts from the lighter tapping machine.

These results are from the evaluations made by our initial cohort of 31 subjects. This was too small a group to permit any clear indications of differences between groups with significantly different Noise Sensitivity or Privacy Rating — there were simply too few in the different divisions of sensitivity.

However, one small but significant difference we observed was that women consistently judged the differences between the pairs to be smaller than the judgements made by men (this was approximately a 5% difference).

When divided by age, we found this had no effect on judgements of the tapping machine impacts, but for the heavy impacts i.e. the Japanese ball drops, the under 30's group consistently judged differences between the pairs to be about 12 % greater than the over 40's group.

Correlations with Objective Measures

Eventually it is hoped that these experiments will help clarify and refine the objective measures used for impact insulation. The issue here is that the standard impact insulation measures – even with the ISO frequency extension down to 50 Hz – don't cover the full bandwidth that we have covered in these experiments and which,

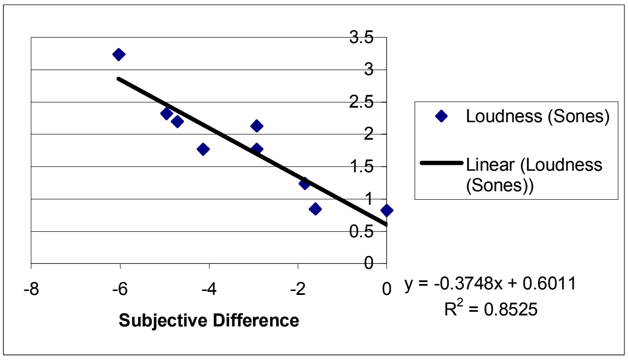

Figure 4: Loudness of the presentations of the Japanese Standard Impact Ball versus the subjective differences between the floors.

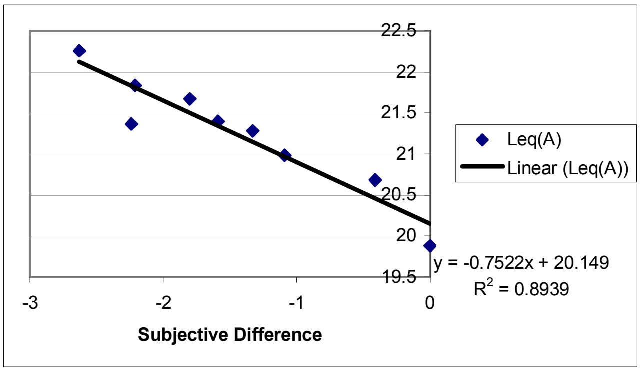

Figure 5: A-weighted SPL of the presentations of the Japanese Standard Impact Ball versus the subjective differences between the floors.

importantly, happens in practice.

However, if we use Loudness in Sones and A-weighted SPL these are both standardised measures which can be extended to include all the low frequencies, and having done this extension, we used them to see how well they would rank the floors.

When we used the mean values of judgements from all our subjects we found surprisingly good linear correlations for both loudness and A-weighted sound pressure level and the rankings from the subjective judgments (Figs 4 and 5)

It is worth emphasising that, as Table 2 shows, single figure ratings (e.g. $L_{n,w}$, $L_{n,w + Ci}$ [4]) rank the floors differently for different types of impact source.

This lends weight to the idea that specifictions for required impact performance (as for example in national building codes) cannot be stated satisfactorily in terms of a single figure description.

Did We Succeed in the Project?

The preference rankings consistently show floor 9 to be either very close to or better than the concrete reference construction over the range of impacts and floor coverings we used. However, it is the heavy impacts which are the most likely to expose the low frequency weaknesses of light timber floors so most weight should be given to those results.

In order to conclude whether these differences are likely to mean that floor 9 and the concrete reference differ in acoustic comfort they provide, we have referred to Johansson's recent work [5] on Drum sound from floors and Guski's work[6] on Psychological methods for evaluating sound quality and assessing acoustical information.

Ball drop	
Ranking by Preference	**Ranking by Subjective Difference**
Ref fl 1	Ref fl 1
fl 9 2	fl 9 2
fl 8 3	fl 8 3
fl 19 4	fl 19 4
fl 18 5	fl 20 5
fl 14 6	fl 3 6
fl 20 7=	fl 14 7
fl 3 7=	fl 18 8
fl 2 7=	fl 2 9

Tapping machine	
Ranking by Preference	**Ranking by Subjective Difference**
fl 9 1=	fl 9 1
fl 8 1=	fl 8 2
fl 18 1=	fl 18 3
fl 3 1=	fl 3 4
fl 19 1=	fl 14 5
fl 14 6	fl 19 6
fl 20 7	fl 2 7
fl 2 8	fl 20 8
Ref fl 9	Ref fl 9

Walking (bare floor)	
Ranking by Preference	**Ranking by Subjective Difference**
fl 9 1	fl 9 1
fl 3 2	fl 3 2
Ref fl 3	Ref fl 3
fl 18 4	fl 8 4
fl 8 5	fl 18 5
fl 14 6	fl 14 6
fl 20 7=	fl 20 7
fl 19 7=	fl 19 8
fl 2 7=	fl 2 9

Table 2: Rank ordering of floor preference for different impact types.

Ball drop							
Ranking by Preference	Ranking by Subjective Difference	Ranking by Ln,w	Ranking by Ln,w + Ci	Ranking by Ln,w + Ci (50-2500)	Ranking by IIC	Ranking by LAeq	Ranking by Sones
Ref fl 1	Ref fl 1	fl 3 1	fl 3 1	fl 3 1	fl 9 1	fl 9 1	Ref fl 1
fl 9 2	fl 9 2	fl 9 2	fl 9 1=	fl 8 1=	fl 3 2	Ref fl 2	fl 9 2
fl 8 3	fl 8 3	fl 8 3	fl 8 3	fl 9 3	fl 8 3	fl 8 3	fl 8 3
fl 19 4	fl 19 4	fl 14 4	fl 14 4	Ref fl 4	fl 14 4	fl 20 4	fl 20 4=
fl 18 5	fl 20 5	fl 18 5	Ref fl 5	fl 14 5	fl 18 5	fl 3 5	fl 3 4=
fl 14 6	fl 3 6	fl 19 6	fl 18 6	fl 18 5=	fl 19 6	fl 19 6	fl 19 6
fl 20 7=	fl 14 7	fl 2 7	fl 19 7	fl 19 5=	fl 2 7	fl 14 7	fl 14 7
fl 3 7=	fl 18 8	Ref fl 8	fl 2 8	fl 20 8	Ref fl 8	fl 18 8	fl 18 8
fl 2 7=	fl 2 9	fl 20 9	fl 20 9	fl 2 8=	fl 20 9	fl 2 9	fl 2 9

Table 3: Subjective versus objective rankings for Japanese Standard Impact ball

Tapping machine							
Ranking by Preference	Ranking by Subjective Difference	Ranking by Ln,w	Ranking by Ln,w + Ci	Ranking by Ln,w + Ci (50-2500)	Ranking by IIC	Ranking by LAeq	Ranking by Sones
fl 9 1=	fl 9 1	fl 3 1	fl 3 1	fl 3 1	fl 9 1	fl 9 1	fl 9 1
fl 8 1=	fl 8 2	fl 9 2	fl 9 1=	fl 8 1=	fl 3 2	fl 8 2	fl 8 2
fl 18 1=	fl 18 3	fl 8 3	fl 8 3	fl 9 3	fl 8 3	fl 3 3	fl 3 3
fl 3 1=	fl 3 4	fl 14 4	fl 14 4	Ref fl 4	fl 14 4	fl 14 4	fl 14 4
fl 19 1=	fl 14 5	fl 18 5	Ref fl 5	fl 14 5	fl 18 5	fl 19 5	fl 19 5
fl 14 6	fl 19 6	fl 19 6	fl 18 6	fl 18 5=	fl 19 6	fl 18 6	fl 18 6
fl 20 7	fl 2 7	fl 2 7	fl 19 7	fl 19 5=	fl 2 7	fl 2 7	fl 2 7
fl 2 8	fl 20 8	Ref fl 8	fl 2 8	fl 20 8	Ref fl 8	fl 20 8	fl 20 8
Ref fl 9	Ref fl 9	fl 20 9	fl 20 9	fl 2 8=	fl 20 9	Ref fl 9	Ref fl 9

Table 4: Subjective versus objective rankings by for ISO Tapping Machine

Walking on bare floor							
Ranking by Prefer-ence	Ranking by Subjec-tive Differ-ence	Ranking by $L_{n,w}$	Ranking by $L_{n,w + Ci}$	Ranking by $L_{n,w + Ci}$ (50-2500)	Ranking by IIC	Ranking by L_{Aeq}	Ranking by Sones
fl 9 1	fl 9 1	fl 3 1	fl 3 1	fl 3 1	fl 9 1	fl 9 1	fl 9 1
fl 3 2	fl 3 2	fl 9 2	fl 9 1=	fl 8 1=	fl 3 2	Ref fl 2	Ref fl 2
Ref fl 3	Ref fl 3	fl 8 3	fl 8 3	fl 9 3	fl 8 3	fl 8 3	fl 8 3
fl 18 4	fl 8 4	fl 14 4	fl 14 4	Ref fl 4	fl 14 4	fl 2 4	fl 3 4
fl 8 5	fl 18 5	fl 18 5	Ref fl 5	fl 14 5	fl 18 5	fl 3 5	fl 2 5
fl 14 6	fl 14 6	fl 19 6	fl 18 6	fl 18 5=	fl 19 6	fl 14 6	fl 14 6
fl 20 7=	fl 20 7	fl 2 7	fl 19 7	fl 19 5=	fl 2 7	fl 18 7	fl 18 7
fl 19 7=	fl 19 8	Ref fl 8	fl 2 8	fl 20 8	Ref fl 8	fl 20 8	fl 20 8
fl 2 7=	fl 2 9	fl 20 9	fl 20 9	fl 2 8=	fl 20 9	fl 19 9	fl 19 9

Table 5: Subjective versus objective rankings for walking on the bare floors

In this work they recommend dividing preference scales into only 5 categories and if we do that for our results then we find floor 9 and the reference floor falling in the same category and therefore arguably subjectively similar.

In addition we can note that *acoustic quality categories* and *classes of acoustical comfort* found in Norwegian [7] and German [8] standards are categories which span a 4-5 dB range. Also Hagberg's Meta-analysis which he presented at ICA 2004 [9] distinguishes a 4 dB difference as needed for there to be a noticeable change.

Thus the mere 1 dB difference in A-weighted SPL we measured between floor 9 and the reference concrete floor suggests they are well within the same category.

We conclude therefore that our testing has demonstrated that floor 9 (see Appendix 1 for construction details) will provide the same degree of acoustic satisfaction as the concrete reference construction when used as an inter-tenancy floor.

Conclusions

1. We've created a test facility for the reproduction and comparison of floor impact sounds which provides realism in both visual and auditory dimensions (including infrasound reproduction)
2. The first use of the test facility has demonstrated that we can build timber-based, light weight floor ceiling systems which give a performance subjectively equivalent to a heavy concrete floor slab (plus suspended ceiling) in the critical low frequency region, and
3. We've demonstrated that a loudness calculation suitably extended to include the very low frequencies gives a reasonably acceptable means for rank ordering light timber floor-ceiling constructions for their ability to insulate against both heavy and lightweight "hard" impacts.

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