Measuring L_n without using a tapping machine?

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ABSTRACT

We propose an alternative method for measuring L_n which we suggest will make field testing of buildings easier and more attractive to do. Although field testing is essential for quality control during construction, and to demonstrate conformity with building code requirements, it has challenges which make it unpopular. In particular the tapping machine's fixed power-output and hence L_n's lack of immunity to interference from background noise rules out its use during construction. In addition the formal measurement procedure can be time consuming, it involves the cost of a tapping machine and it requires a specialist acoustical engineer. In our method L_n is inferred from a measurement of the airborne sound insulation (R) by using a relationship between R and L_n. R can be measured by either using a high power source, or by coherent averaging of a deterministic signal, hence background noise interference is obviated. An impact on the floor is still necessary to determine the effect of its actual impedance. However our method uses a single hand-held hammer and infers the effect of impacting with the tapping machine by measuring the reaction force on the hammer.

Keywords: Impact Insulation, Tapping machine I-INCE Classification of Subjects Number(s): 72.9

1. INTRODUCTION

We describe the first part of a project in which we examine the possibility of developing an easy method for screening impact sound insulation in buildings. The aim is to avoid the burdensome task of carrying around a tapping machine, to provide a technique which has immunity from contamination by site noise and to reduce the number of sound measurements required for certifying floors for building code compliance.

In New Zealand we are seeing, in common with other developed countries, the intensification of our cities with more of our population accommodated in higher density forms of dwellings. This means greater numbers of flats, apartments and townhouses being built. A common feature is that the acoustic insulation and acoustic privacy between occupancies depends on the performance of the building structure that is shared in common between the dwellings. Impact sounds are a very common cause of complaints in lightweight timber framed buildings (a construction form widely used in New Zealand) and we wish to encourage moves to improve building performance by providing a convenient screening method. This can be used for quality control and fault diagnosis as well as a means for verifying comfort categories when categories of acoustic comfort for buildings become standardised.

2. CONCEPT

The heart of the proposal is to obviate a need for measuring the sounds produced by impacts on the structure (either from the standard tapping machine or from any other source) and use its airborne sound reduction index to infer the impact sound insulation.

If we dispense with the tapping machine and hence remove the need to measure impact sound pressure levels there are significant advantages. Not only do we reduce time and cost for carrying out a measurement (as Ln measurements are unnecessary) but there are also gains for testers. First they are saved from transporting a heavy tapping machine around on site and secondly they are freed from concerns over poor signal-to-noise ratio from the fixed power tapping machine when on a noisy site.

Since the mechanism for impact noise transmission through a floor is largely the same as that which determines the airborne sound transmission it is not surprising that relationships should exist between

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them. If the radiated power from a structure is assumed proportional to the square of the force exciting it, and also that there is a proportionality between structural energy and reverberant energy in a room, then a reciprocity argument can be used to derive a simple relationship between impact sound pressure level and sound reduction index. This has been published in papers by Heckl and Rathe [1] and Ver [2].

Heckl and Rathe showed that that sum of the sound reduction index and the normalised impact sound pressure level can be quantified as a function of the force spectrum, $F(f_c)$, of an impact of the floor where f_c is the centre frequency of 1/3 octave bands:

$$R + L_n = 10\log\left(\frac{k^2 F^2(f_c)}{4\pi A_0 p_0^2}\right) \tag{1}$$

Here the normalised impact sound pressure level is that produced by excitation with the standard tapping machine and R and L_n are measured in accordance with ISO 140 [3].

Substituting $F(f_c)$ as $MA(f_c)$, where M is the mass of the impact hammer (= 0.5 kg) and $A(f_c)$ is the acceleration spectrum of the hammer impact,the equation above can be re-written as:

$$R + L_n = 10\log\left(\frac{\pi f_c^{\,3}}{A_0 p_0^2 (331.3+0.606T)^2}\right) + 10\log\left(\frac{M^2 A^2(f_c)}{2^{\frac{1}{3}}}\right) \tag{2}$$

$$L_n = 10\log\left(\frac{\pi f_c^{\,3}}{A_0 p_0^2 (331.3+0.606T)^2}\right) + 10\log\left(\frac{M^2 A^2(f_c)}{2^{\frac{1}{3}}}\right) - R \tag{3}$$

where $A_0 = 10\ \mathrm{m}^2$, $p_0 = 20\ \mu\mathrm{Pa}$, and T is the environment temperature. $A(f_c)$ is the only unknown in the expression and can be measured by an accelerometer.

This relationship between R and L_n doesn't hold if the airborne sound and the impact sound can travel via significantly different paths – for example if the airborne sound finds an unsealed hole in the floor or excites important flanking transmission through surrounding walls.

Also (as pointed out by Brusnkog [4]) the relationship holds only for situations where the energies can be expressed as spatial means of the squared response, in effect this means where there are diffuse fields and high modal overlap. Hence we can expect that it will not be applicable below some low frequency limit.

Where a floor construction has a resilient covering - as is often necessary – we need to know how to make use of equation 3 to give a prediction of L_n to account for the interaction of the tapper hammer with the covered floor.

In the case of the modest impacts delivered by a tapping machine the response of a rigid floor may be assumed to be linear, but this is not generally the case for the resilient floor covering [5]. The value of a non-linear theory describing the response of specific, custom installed covering tested in the field would be little – even if it were available. What is needed is verification of the response of the whole floor to the standard tapping machine.

Given the likely non-linearity of the covering's response to impacts there is no alternative to making a measurement of the response to an impact which matches that of a tapper hammer.

At this initial stage of the work we have assumed we are dealing with building constructions where airborne sound flanking transmission is insignificant compared with transmission through the floor being tested. Thus the focus of this project has been to show that L_n can be successfully predicted for a rigid or resiliently covered homogenous floor based on information about the force when impacting the floor. This has involved developing a system for measuring the reaction force on the hammer when it hits the floor.

3. MEASUREMENT PROCEDURE

Since the energy radiated as sound by the floor is delivered by the tapping machine hammer the effect of a non-rigid floor or a resilient covering will be seen in the force spectrum delivered by the hammer on the tested floor. The force spectrum can – on the basis of Newton's Law - be measured/monitored in terms of the reaction force on the hammer. We have used an accelerometer attached to a single tapping machine hammer to measure this reaction force.

4. MEASUREMENTS

Figure 1 shows how well the sum of R and L_n, predicted by the Heckl and Rathe relationship with the force measurement from the hammer (eq.2), matches the sum of the *R* values with the normalised impact SPL measured (according to the full ISO 140 procedure) on a rigid high impedance floor (140 mm reinforced concrete floor slab separating two reverberation chambers).

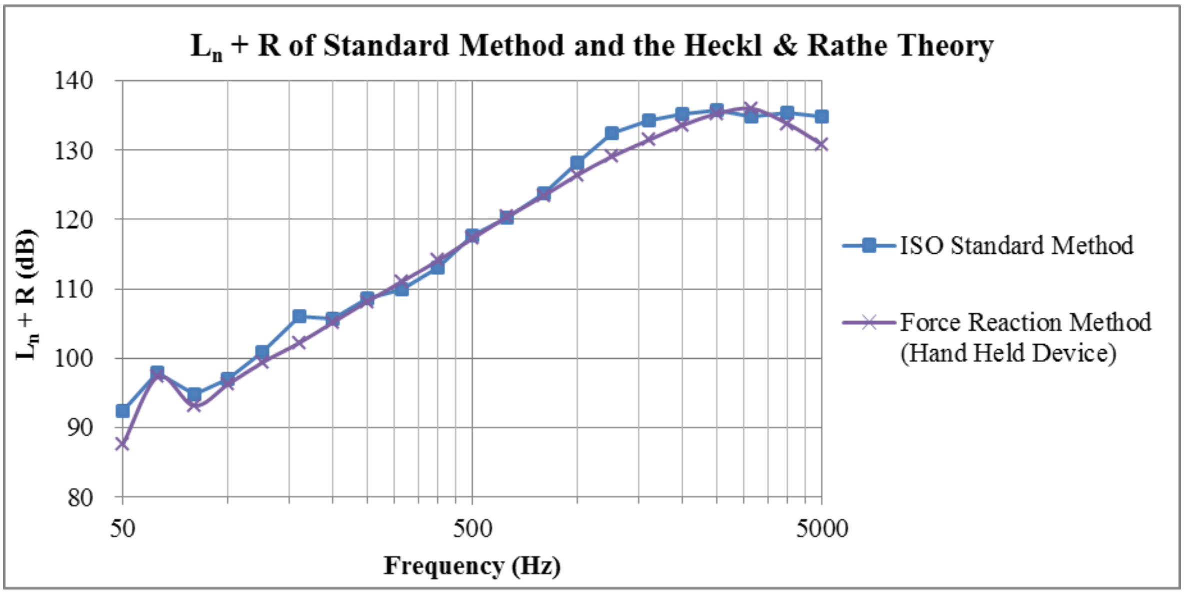

Figure 1 - Ln + *R* of the Standard Method and the Heckl & Rathe Theory

Although the match is close it is imperfect at the highest frequencies. However, the high frequency deviations produce no significant difference between the predicted and measured single figure values (either $L_{n,w}$ or $L_{n,Tw}$) for the floor.

The comparisons of the measured and predicted L_n values for two sample floor coverings shown in figures 2 and 3 provides a validation of the spectrum modification technique.

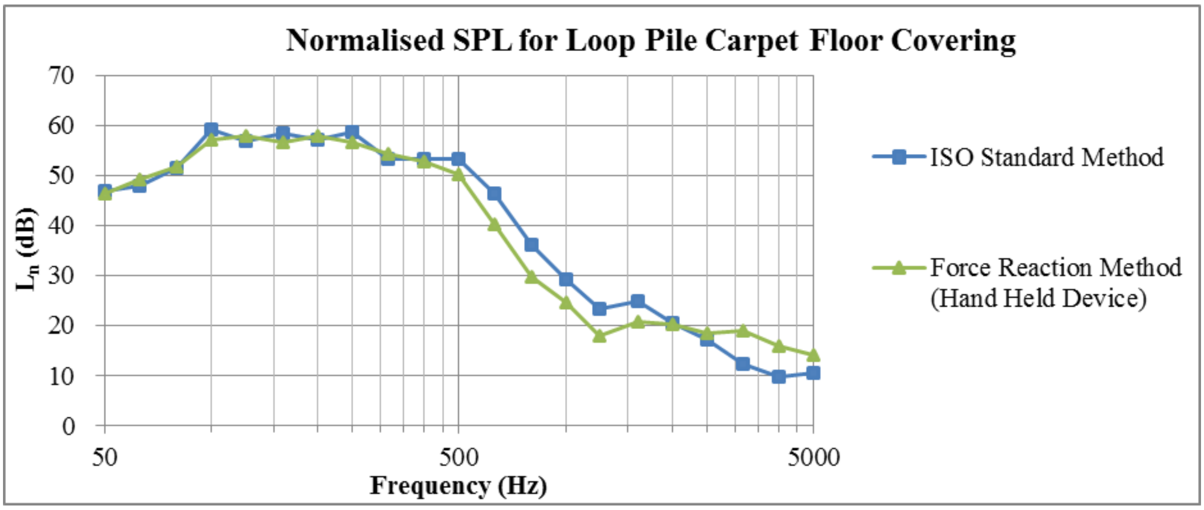

Figure 2 - L_n values for loop pile carpeted floor

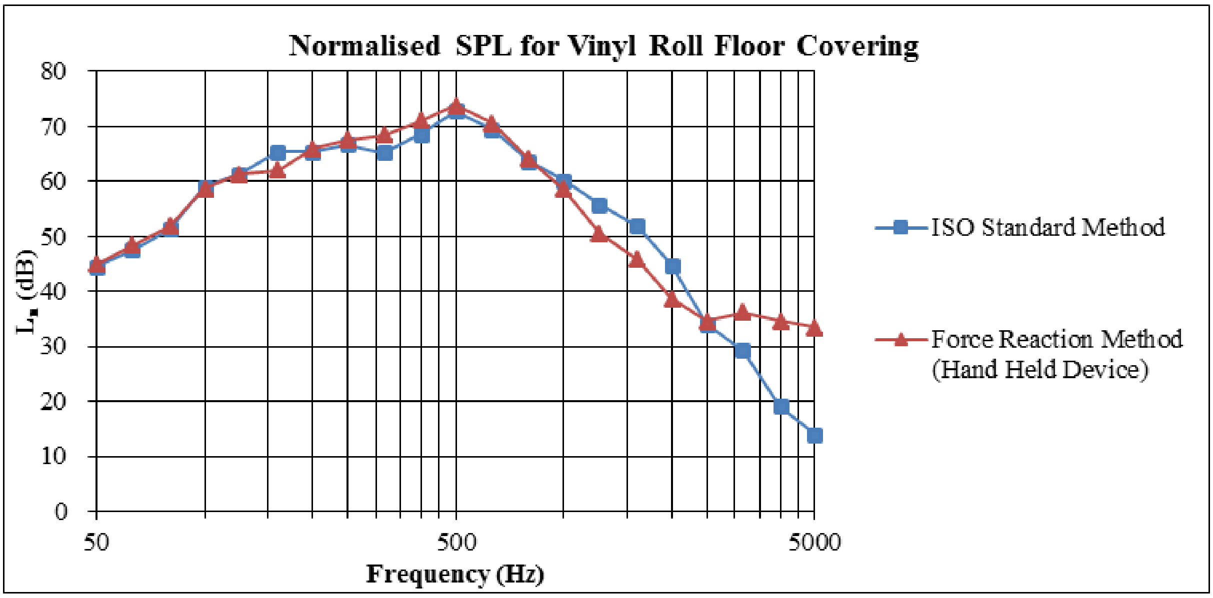

Figure 3 - L_n values for vinyl roll covered floor

5. IMMUNITY TO HIGH BACKGROUND NOISE LEVELS

A clear advantage the reaction force technique has over the standard ISO method is that it is essentially insensitive to any level of ambient sound. A measurement of the airborne sound insulation, *R*, is still required but, since this is made using a loudspeaker source, a coherent averaging technique using MLS or chirp signals can be used to obtain an adequate signal to noise ratio. Figure 4 shows the measured and predicted L_n values when the reaction force technique is used in an extreme environment of airborne sound levels of 103 dB(A).

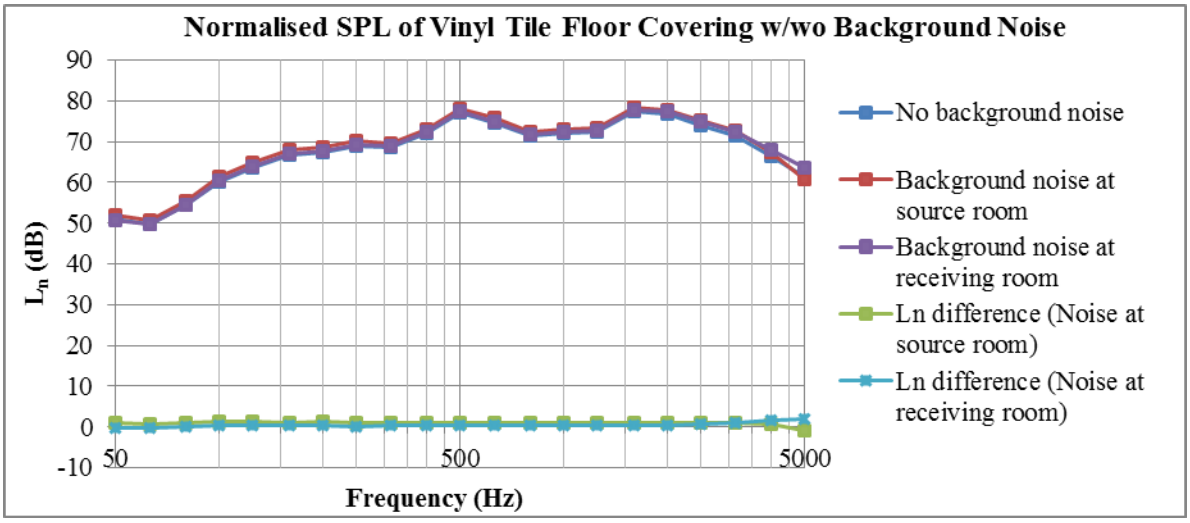

Figure 4 - L_n values of vinyl tile covered floor with and without high level background noise

6. SIMPLIFICATION OF THE EQUIPMENT

The results shown in figures 2 and 3 labelled 'ISO Standard Method' were obtained using a full ISO-conforming tapping machine which is a cumbersome item of equipment (weight around 14 kg) to carry around and move on floors. However, with today's instrumentation capable of measuring L_{eq} values a lighter tapping machine comprising a single hammer can replace the 5 hammer machine as we have demonstrated [6] In that work we developed the Uni-Tapper (see Figure 5) which is considerably lighter than the standard 5 hammer tapper and the accelerometer to measure the reaction force can be attached to it.

Figure 5- Single hammer -Uni-tapper

However, a motorised hammer is not required for measuring the reaction force. We have sought further weight reductions and greater flexibility by incorporating a single tapper into a hand-held hammer. A hinged design (see Figure 6 – the hinge is circled) provides for near-free fall of the tapper and a simple ultrasonic proximity measuring system has been adapted for measuring the impact velocity as required to match that required in the ISO Standard.

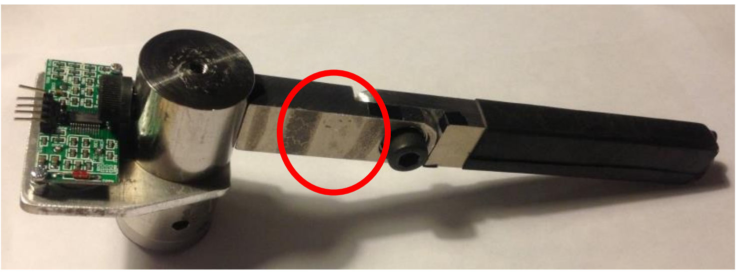

Figure 6- Mechanical design of the hand held impact hammer device – the circle shows the hinge allowing near-free fall of the hammerhead

The simple ultrasonic proximity system could not work rapidly enough for direct measurement of the impact velocity but software was developed in Matlab which provided adequate feedback to a user as to when they had made an impact with the correct velocity. Details for this will be presented.

It was found that the manual skill required for producing consistently repeatable impacts of the right velocity was acquired very quickly, though significant improvements in hardware capability and software efficiency can be expected to dramatically improve user experience from our current prototype. Table 1 shows a comparison of results for a range of floor coverings obtained by the full ISO method with results using the hand held hammer. The single figure values ($L_{n,w}$) using the prototype device match those obtained with a tapping machine within the repeatability values for standard measurements.

Table 1 - ISO 717-2 Single Value Ratings for the Standard Method and Hand Held Device

$L_{n,w}$ Rating (ISO 717-2)	**ISO Standard**		**Hand Held**	
	Mean	Deviat	Mean	Deviat
Bare Concrete	81.2	1.1	79.6	0.9
Tiled Carpet	48	0	47.2	0.4
Tiled Carpet	51.2	0.4	52.2	0.4
Loop Pile	52.8	0.4	52.8	0.4
Cork	60.4	0.9	59	0
Vinyl Tile	78	0	77.2	0.4
Vinyl Roll	60	0	61	0

7. CONCLUSIONS

A prototype device has been demonstrated which, using airborne sound insulation measurements in combination with measurements of the reaction force measured on a hand-held impact hammer, has the potential to replace the need for standard tapping machine measurements. An added advantage to obviating the requirement of a tapping machine is that the procedure can be used on site whatever the level of background noise.

REFERENCES

1. Heckl, M. and Rathe, E.J. "Relationship between the Transmission Loss and and the Impact Noise Isolation of Floor Structures" *Journal of the Acoustical Society of America* **35** (11) 1825-1830, 1963
2. Ver, I. L."Relationship between the Normalised Impact Sound Pressure Level and Sound Transmission Loss" *Journal of the Acoustical Society of America* **50** 1414-1417, 1971
3. ISO 140-7 Acoustics -- Measurement of sound insulation in buildings and of building elements -- Part 7: Field measurements of impact sound insulation of floors.
4. Brunskog, J "Prediction of Impact Sound Transmission of Lightweight Floors" *Lund University Engineering Acoustics LTH*Coden:LUTVDG/(TVBA-3105)/1-137/1999
5. Lindblad, S. "Impact Sound Characteristics of Resilient Floor Coverings" *Lund Institute of Technology, Division of Building Technology, Bulletin* 2, 1968
6. Dodd, G., Schmid, G. and Li, M. "Can Screening Measurements of Building Insulation be made Easier and more Convenient?" *Journal of Building Acoustics* **16** (1) 67-83, 2009