New Zealand Acoustics, vol. 25, no. 1, pp. 20-24, 2012

Frequency Behaviour of Basic Floor Structures

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Abstract

In order to obtain reliable estimates of the impact sound insulation between rooms, it is necessary to know the acoustic performance of each element composing the floors. The contribution of the flanking transmissions, the attenuation of floating floors and the weighted normalized impact sound pressure level of the basic structure need to be determined in order to apply the simplified calculation method according to the EN ISO 12354-2 standard. With the aim of verifying the range of validity of the calculation method proposed by the EN ISO 12354-2 standard for typical basic beam floor structures, a research based on on-site measurements was conducted. This paper provides an analysis in terms of spectrum trend, predicted average weighted normalized impact sound pressure level and reduction of impact sound pressure level obtainable with a generic floating floor typology. The study can represent a starting point for a correct estimation of the impact sound insulation in new buildings and renovation plans.

INTRODUCTION

The aim of this work is to analyse the acoustic design of the common basic beam floor constructions in building technology: the basic wooden beam floor structures and concrete beam with perforated brick structures. The issue of the performance of the former type of structure is frequent in renovations of historical buildings. In addition, for basic wooden beam floor structures, there are no empirical calculation methods to evaluate the impact sound level, while for basic concrete beam with perforated brick structures the available method is not reliable. Therefore, it is difficult to estimate the impact sound insulation for complete horizontal partitions.

DESCRIPTIONS OF INVESTIGATED STRUCTURES

The investigated horizontal partitions are composed of two parts: the structural one (basic beam floor) and the upper one (floating floor). The former can usually be built as a heavyweight or lightweight part. The heavyweight basic floor part usually consists of concrete (solid floor or beam floor); the lightweight basic floor part usually consists of:

- beam and pot floor structures (where the pots are composed by perforated bricks);
- wooden frame floor structures.

The beam and pot floor structures (*bpf*) are typically composed of a structural part (reinforced concrete beams 12-14 cm width, together with reinforced concrete slab 4-6 cm thickness) and perforated bricks or polystyrene blocks (16-28 cm thickness) as shown in Figure 1.

The complete basic floor structure has a usual density of about

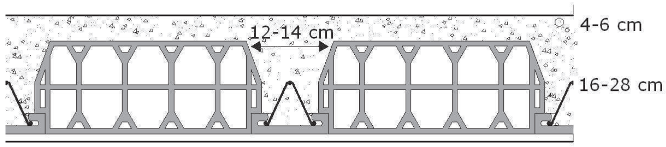

Figure 1. Typical beam and pot basic floor structure

160-400 kg/m^2. The lightweight wooden frame basic floors (*lwf*) are typically made of wooden beams with different spaces between beams, wood boarding and light concrete slab with 4-6 cm thickness (Figure 2).

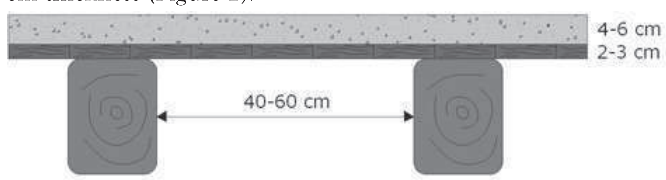

Figure 2. Lightweight wood basic floor structure

The role of the concrete slab is to supply appropriate stiffness and strength to the structure, in order to perform the function of the diaphragm drive for the distribution of horizontal forces and to protect the underlying resistance structure against the risk of fire from spaces above. The concrete slab has a usual density of about 1500 kg/m^3 or more.

This kind of lightweight structure often fails to provide adequate sound insulation (both for impact and airborne sound insulation) compared with concrete slabs or beam and pot structures. In order to find out how the frequency spectrum trend of the bpf and the *lwf* systems can influence the determination of the impact sound insulation index of the complete horizontal partitions, adequate on-site measurements were conducted.

INVESTIGATION ON IMPACT SOUND PRESSURE LEVEL SPECTRUM OF THE BASIC FLOOR CONSTRUCTIONS

For concrete slabs (homogeneous floor construction), the equivalent weighted normalized impact sound pressure level can be determined with the simplified model equation of the EN ISO 12354-2/2000 standard [2]:

$$L_{n,w,eq} = 164\text{-}35 \log(m') \quad \text{dB} \qquad (1)$$

where m' is the mass per unit area of homogeneous floor construction. On-site measurements demonstrate good correspondence between the equation and the obtained results [3-4].

The EN ISO 12354-2 standard extends the use of equation (1) to bpf structures, where the pots are composed of perforated bricks, by including this type of structure among the homogeneous constructions, as reported in Annex B (Figure 3).

However, on-site measurements carried out on a significant number of bpf structures have shown how the equation reported in EN ISO 12354-2 standard for the calculation of $L_{n,w,eq}$ index underrates the results [5]. The investigation demonstrates how the mean value of the frequency spectrum trend could be represented with the following equation:

$$L_{n,w,eq} = 16.4l\ g(f) + 26 \text{ dB} \qquad (2)$$

The calculated linear regression coefficient is equal to 0.98 and the average evaluation index of L_{nw0}, measured according to EN ISO 717-2 [6], is equal to 87 dB with a standard deviation of 2.4 dB. All the measured spectra $L'_{ni,0}$ are reported in Figure 4.

The results also demonstrate that there is no direct relation between the $L_{n,w,eq}$ quantity and the mass per unit area m' of the basic floor structure (Table 1).

For *lwf* structures the estimation of acoustic performance with the simplified model equation of the EN ISO 12354-2 standard is not applicable. The only way to know the acoustic behaviour is to carry out on-field measurements.

The first obtained results were presented in [1] and [7]. Further investigations on *lwf* structures were carried out in building yards in very different geographic locations (implying use of the same technology but different manpower). These were composed of:

- wood beams with 60 cm spaces between beams;
- wood boarding with 2.5 cm thickness;
- concrete slab with 6-8 cm thickness.

The obtained results are shown in Figure 5.

The mean value of the frequency spectrum trend could be represented with the following equations:

$$L_{n,eq,avg} = 9.7\log(f)+52 \text{ dB} \quad \text{for } f<1600 \text{ Hz} \qquad (3)$$

$$L_{n,eq,avg} = (-7.4)\log(f)+106 \text{ dB} \quad \text{for } f>1600 \text{ Hz} \qquad (4)$$

The calculated linear regression coefficient is 0.97 for both the equations and the average evaluation index L_{nw0}, measured according to UNI EN ISO 717-2, is equal to 87 dB with a standard deviation of 2.9 dB.

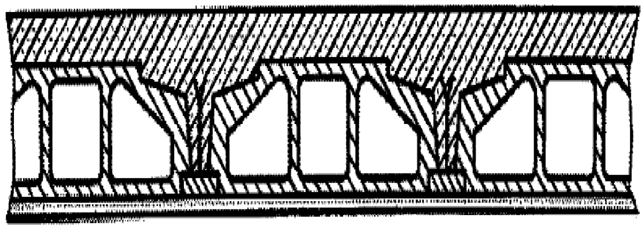

Figure 3. Type of basic floor construction as identified by standard EN ISO 12354-2-Annex B: beam and pot category

The typical spectrum of the *lwf* structures can determine different values of the weighted normalized impact sound pressure level also for structures with similar mass and geometry (Figure 6).

No relation between the calculated evaluation index L_{nw0} and the mass per unit area of each structure was found.

Table 1 Weighted normalized impact sound pressure level values as a function of mass per unit area values of the beam and pot basic floor structures

Basic floor height	m' [kg/m^2]	measured $L'_{n,w}$ (dB)	$L'_{n,w}$ (dB) ST12354-2
16+4	230	84-87	81
18+4	255	83-88	80
20+4	275	83-89	79
24+4	305	88	77
28+4	334	88-91	76

INFLUENCE ON THE WEIGHTED NORMALIZED IMPACT SOUND PRESSURE LEVEL VALUE

Figure 7 shows a comparison between the mean value of the frequency spectrum trend for both beam and pot and lightweight wood basic floor structures.

The different structures have very different mass values (about 100 kg/m^2 for *lwf* and about 280 kg/m^2 for *bpf*).

The overall impact sound pressure level for the two spectra is quiet different (L_{eq} = 90.9 dB for *lwf* and L_{eq}=88.4 dB for *bpf*); the results of the weighted normalized impact sound pressure level are nearly the same ($L_{n0,W}$ = 86.8 dB for *lwf* and $L_{n0,W}$ = 86.5 dB for *bpf*).

Both spectrum trends shown in figure 7 increase with the frequency domain. The curve slope is greater for *bpf* structures. For *lwf* structures the slope of the curve increases until 1600 Hz and then decreases with a similar slope until 5000 Hz.

The *lwf* construction irradiates more energy at low frequency than the bpf one. This confirms, as expected, different modal behaviours of the two types of structure [8].

The reference curve (ISO 717-2) penalizes the high frequency spectrum components. This is demonstrated with the comparison between the frequency spectrum of a typical *bpf* structure (on site measurements) and a concrete basic floor construction with 14 cm thickness (laboratory measurements): the overall impact sound pressure level for the two structures is the same ($L_{eq} \approx 86.8$ dB), but the results of the weighted normalized impact sound pressure level are different: $L_{n,w} = 83$ dB for concrete slab, $L'_{n,w} = 85$ dB for beam and pot basic floor structure (Figure 8).

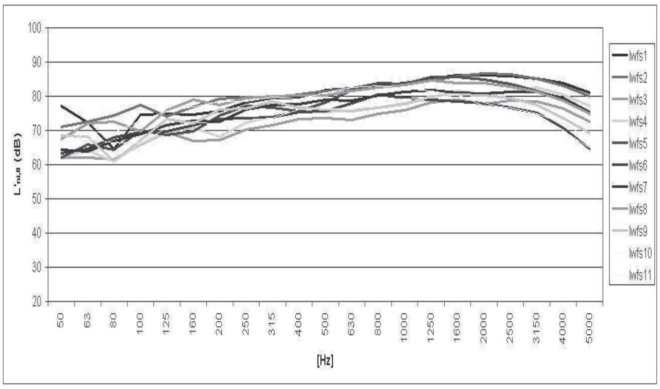

Figure 5. Frequency spectra of measured lightweight wood basic floor structures.

INFLUENCE ON THE SPECTRUM ADAPTATION TERM

The assessment of the impact sound pressure level by $L_{n,w}$ index does not take adequately into account the peak levels at individual frequencies. For this reason, the spectrum adaptation term C_I was introduced by ISO 717-2 standard, calculated as follows:

$$C_I = L_{n,sum} - 15 - L_{n,w} \quad \text{dB} \qquad (5)$$

where $L_{n,sum}$ is the measured level sum in decibels. The standard refers that the spectrum adaptation term will be slightly positive for the wood floors, without concrete slab, with low frequency dominant peaks.

For the measured *bpf* structures the spectrum adaptation terms

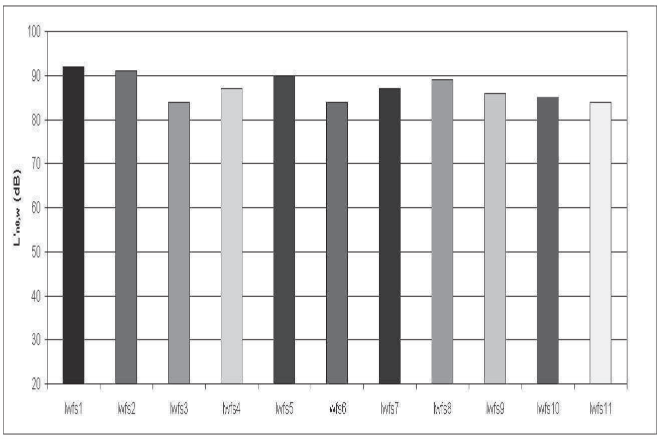

Figure 6. Comparison of the calculated evaluation index L_{nw0} for lightweight wood basic floor structures.

C_I values are included into the range [-11; -20,2] dB with a mean value of -17,2 dB and a standard deviation of 1,7 dB. This means that $L_{n,sum} \approx L_{n,w}$; in fact both quantities are influenced by the high frequency values.

For the measured *lwf* structures, with concrete slab, the spectrum adaptation terms C_I values are included into the range [-8; -12] dB with a mean value of -12,1 dB and a standard deviation of 1 dB. This fact doesn't agree with the ISO 717-2 standard. As specified in [7] the reason is that adding a concrete slab over the wood boarding reduces the $L_{n,w}$ obtained value because of the

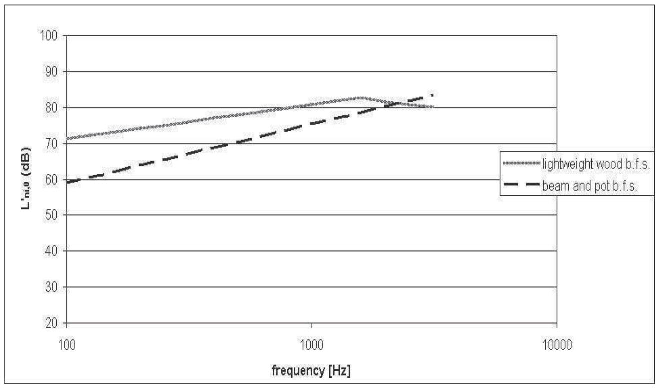

Figure 7. Comparison between the mean value of the frequency spectrum trend for both beam and pot and lightweight wood basic floor structures.

increase in sharp, high frequency sound due to the hard surface.

When using a floating floor as a solution in order to reduce impact noise, the employment of the spectrum adaptation terms C_I is unsuitable; it gives advantage to faulty floating floors, which are structures characterized by a spectrum with high frequency components.

REDUCTION OF IMPACT SOUND PRESSURE LEVEL REFERRED TO THE SAME FLOATING FLOOR TYPOLOGY

Applying the same ΔL theoretical curve of a generic floating floor both to the frequency impact sound pressure level values of all measured *bpf* structures ($L'_{n,eq(i)}$), and to the representative equation of the frequency mean spectrum trend of beam and pot structures (eq. 2), we could obtain differences, in terms of the weighted normalized impact sound pressure level of the complete horizontal structures ($L'_{n,W}$), included into the range ± 2 dB:

$$L'_{n,W} = L'_{n,w,eq(i)} - \Delta L_w = L_{n,w,eq,avg} - \Delta L_w \pm 2 \text{ dB} \qquad (6)$$

The attenuation of floating floors is greater at high frequency, which is the range where the *bpf* structures have more energy. Figure 9 shows an example of attenuation values obtainable at low, medium and high frequency (respectively 125, 500 and 2000 Hz).

Thus, eq. (2) could be used in order to estimate the performance of the complete floor structures. Enforcing the same calculation procedure to the frequency impact sound pressure level values of all measured lwf structures compared with the representative equation of the frequency mean spectrum trend (eq. 3 and 4) the differences are included in the range ± 3 dB (Figure 10).

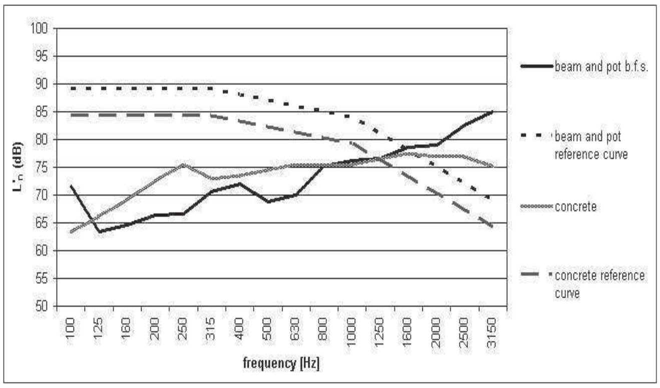

Figure 8. Comparison of the determination of Ln,w for different basic floor structures: concrete slab and beam and pot basic floor structures.

It is interesting to note that applying the same ΔL theoretical curve to the representative equation of the frequency mean spectrum trend calculated for *bpf* structures ($L'_{n0\text{-}bpf}$) and for *lwf* structures ($L'_{n0\text{-}lwf}$), the obtainable values of the weighted normalized impact sound pressure level for the complete floor structure (L_n) are very different: $L_{n\text{-}bpf}$ = 45 dB; $L_{n\text{-}lwf}$ = 53 dB. The difference in terms of the obtainable final value is about 8 dB; the results are shown in figure 11 and 12.

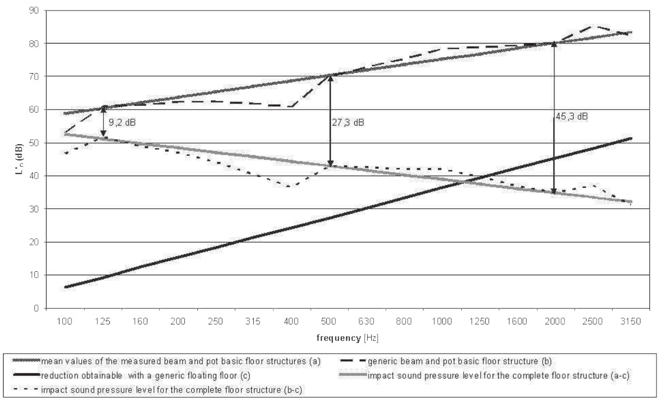

Figure 9. Reduction of impact sound pressure level applied both to the mean values of beam and pot floor structures and to a generic measured spectrum.

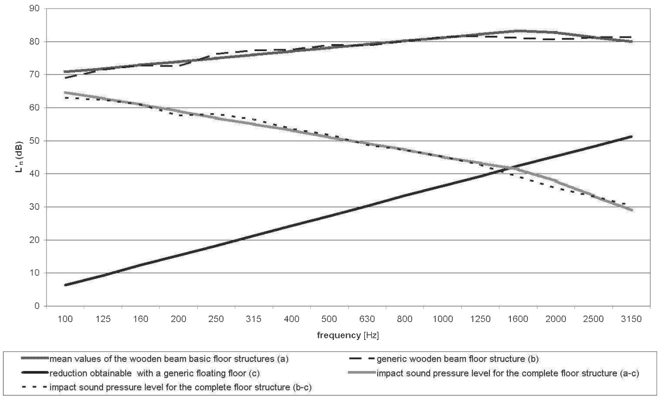

Figure 10. Reduction of impact sound pressure level applied both to the mean values of wooden beam basic floor structures and to a generic measured spectrum.

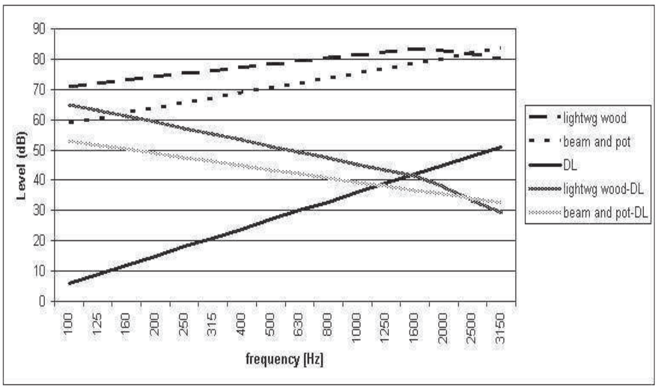

Figure 11. Role of the reduction of impact sound pressure level applied to the mean values of beam and pot basic floor structures and lightweight wood basic floor structures: comparison in terms of frequency trend.

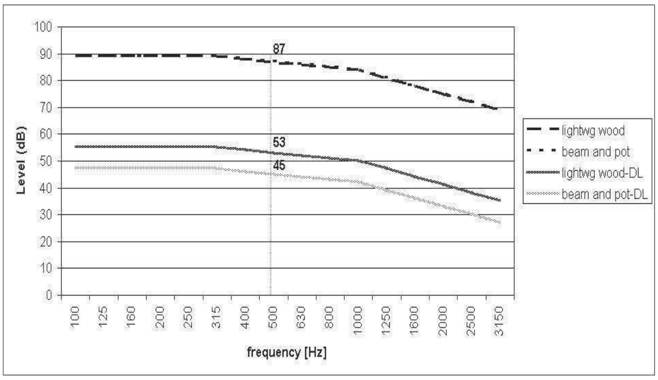

Figure 12. Role of the reduction of impact sound pressure level applied to the mean values of beam and pot basic floor structures and lightweight wood basic floor structures: comparison in terms of reference curve (ISO 717-2).

This means that, for *lwf* systems, higher performances for resilient materials within floating floors are needed. As said above, these structures have more energy at low frequencies; nevertheless in this region the floating floor has less efficiency and this involves a higher impact sound pressure level and index ($L'_{n,w}$), compared with the *bpf* structures and concrete slabs.

With equal contribution of the flanking transmission, the application of the simplified calculation method using only the index values ($L'_n = L'_{n0,w} - \Delta L_w$) would lead to a result of $L'_{n,w}$ = 57 dB for both *lwf* and *bpf* structures, with an underestimation of 4 dB for *lwf* structures and of 12 dB for *bpf* structures.

Applying the same ΔL theoretical curve to the characteristic frequency spectrum trend of a generic concrete laboratory slab (12 cm thickness) with an index value of $L_{n0,w}$ = 83 dB, the obtainable weighted normalized impact sound pressure level values (L_n) for the complete floor structures become Ln-conc=50 dB (Figure 13). The obtainable differences in terms of ΔL are about 33 dB, which is much lower than the previous structures ($\Delta L_{n\text{-}bpf}$ = 42 dB; $\Delta L_{n\text{-}lwf}$ = 36 dB). In fact, while the frequency spectrum of *bpf* and *lwf* structures increases with the frequency domain, the frequency spectrum of concrete slab is flat, so the efficiency of the floating floor at high frequency is much attenuated.

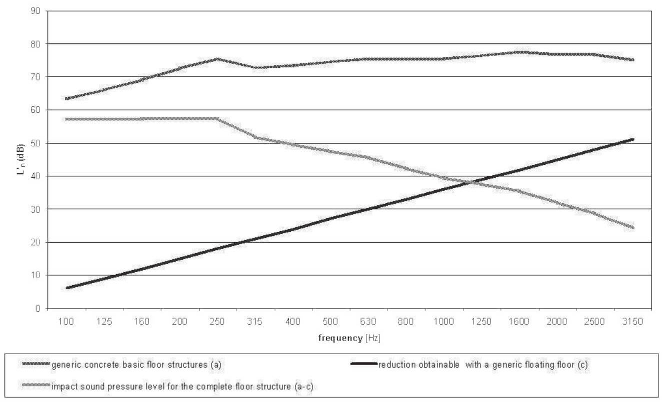

Figure 13. Role of the reduction of impact sound pressure level applied to a generic concrete basic floor structure.

CONCLUSIONS

The investigation of the equivalent weighted normalized impact sound pressure level on wooden beam and beam and pot basic floor constructions shows that there is no relation between the calculated evaluation index and the mass per unit area of each structure. Analyzing the trend of the frequency spectrum for both structure typologies, it was possible to develop an empirical law describing the average performances.

For beam and pot basic floor structures the frequency behaviour is characterized by an increase within the frequency domain; for wooden frame basic floor structures the frequency behaviour is characterized by an increase within the frequency domain until 1600 Hz and a decrease for frequencies up to 1600 Hz. Both structures are characterized by high energy at high frequency; the lightweight wood basic floors have a higher sound energy level at low frequency compared to the beam and pot basic floor structures.

For this reason the employment of the spectrum adaptation terms is unsuitable, in case of use of a floating floor, as a solution to better express the values of the impact noise. For achieving adequate standards of a complete horizontal partition, a more efficient floating floor is needed if the basic floor consists of lightweight wood structures. This analysis assesses the phenomenon of sound insulation for floors with increased accuracy and can therefore provide designers with the correct calculation tools to estimate and fulfil the acoustic requirements needed.

Acknowledgements

The authors wish to thank Mrs. A. Fantini, Mr. M. Taffarel ,Dr. L. Barbaresi, Mr. Enrico Manzi and Mr. Ivano Dal Col for their collaboration.

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