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An engineering method for the calculation of impact sound insulation of wooden floor constructions

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One of the main challenges of wooden residential buildings is sound insulation, especially the impact sound insulation of intermediate floor structures. It has been shown in several studies, that the most annoying source of noise in residential buildings is impact noise from other dwellings. Wooden floor constructions and floor junctions also have a significant effect on the building costs of wooden residential buildings. There is currently no published or validated engineering method for the calculation of impact sound insulation of wooden floor constructions. Such a method has therefore been developed by the acoustical engineering department of AINS Group Ltd. This method is based on an extensive literature study as well as wide practical experience in impact sound insulation measurements and structural engineering. The literature study was carried out to investigate which structural properties have the most and least significant effects on the impact sound insulation of the wooden intermediate floor. Analytic methods have also been used in the calculation. The purpose of this paper is to validate the results of the developed engineering calculation method by comparing calculated and measured results.

1 Introduction

One of the main challenges of wooden residential buildings is sound insulation, especially the impact sound insulation of intermediate floor structures. There is currently no published or validated engineering method for the calculation of impact sound insulation of wooden floor constructions, although the wood building industry has grown remarkably during last few decades.

An engineering method for the calculation of impact sound insulation of wooden floor constructions has been developed by the acoustical engineering department of AINS Group Ltd. This method is based on an extensive literature study concerning parametric measurement results of wooden floors [1] as well as analytical calculation methods. Extensive practical experience in impact sound insulation measurements and structural engineering has also been applied.

The calculation process consists of several phases. The developed engineering method enables the evaluation of the impact sound insulation L_n of a wooden intermediate floor structure in 1/3-octave bands for a frequency range of 50 to 5000 Hz as well as the single-number-quantities $L_{n,w}$ and $L_{n,w} + C_{I\ 50\text{-}2500}$ [2]. The object of this paper is to describe the developed calculation method and validate its accuracy. Wooden bare floors and intermediate floor constructions were calculated with the engineering method and validated by comparison with measurement results.

2 Materials and methods

2.1 Engineering method for calculation of impact sound insulation

The phases of the method and the calculation order are described in the flow chart (Figure 1). The results of phases 1–3 are calculated in 1/3-octave bands from 50 to 5000 Hz. The initial phase includes the calculation of $L_{n,eq}$ of a bare floor and ΔL of a suspended ceiling. The theoretical background of these calculations is discussed in chapters 2.2. and 2.3. In the second phase, the impact sound insulation improvement of a floating floor, an additional floor board such as floor gypsum boards, and floor coverings are evaluated. If available, measured data of improvements can be used too.

The calculation of a combined bare floor with additional boards is carried out by energetic summation of the impact sound reduction indices R_i of these layers. These impact sound reduction indices are calculated according to Scholl [3, 4].

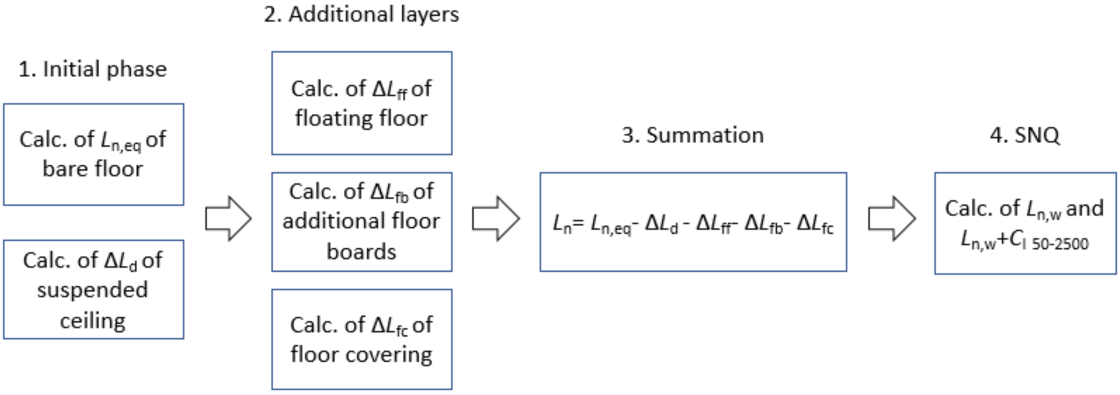

Figure 1: Flow chart of the derived engineering method.

An example of the calculation of the impact sound insulation of a wooden floor has been presented in Figure 2. The figures show the impact sound pressure levels of complete floor structures. Measurement results of the same floors have also been shown in Figure 2. It can be seen, that the calculated results are in good accordance with the measurement results. Both, Floor 1 and Floor 2 were Joist-Plate floors covered with a floating floor. A suspended ceiling was installed in both cases.

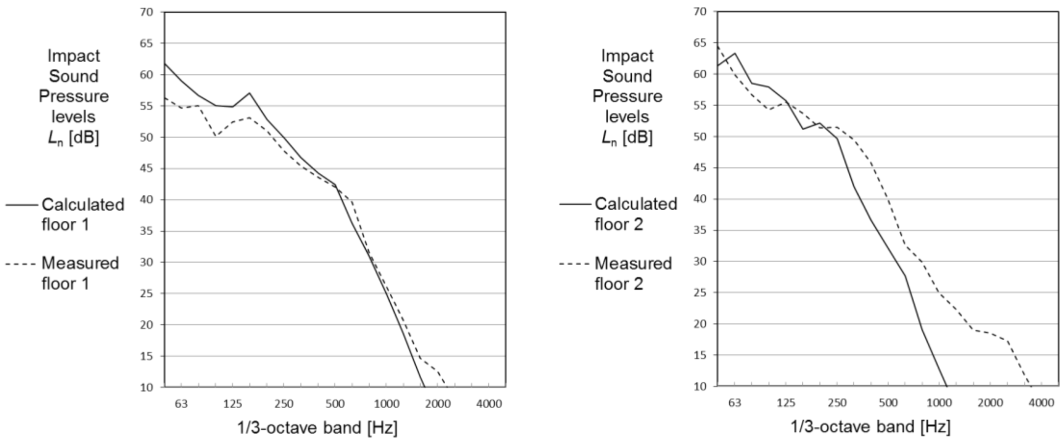

Figure 2: Comparison of calculated and measured impact sound pressure levels. The measurement data is from AINS Group Ltd. database [5]

2.2 Bare floor

A simplified lumped model is used to describe the impact force of an ISO tapping machine hammer on an infinite plate, according to reference [6], a revised theory is presented in reference [7]. The model uses real-value stiffness and resistance parameters and force is calculated in the frequency domain. Since only real values may be inserted, the top plate is considered infinite for driving point impedance. In case of ribbed plates, no additional moment stiffness has been introduced from the beams.

The calculation onwards follows the same principles generally applied for heavy-weight floors given in [8, 9, 10]. The system is considered orthotropic in terms of sound power, sound radiation and average surface velocity. The load-bearing direction has added stiffness due to beams if such are present. The sound radiation of a plate between beams has been taken into account in sound radiation factors. As a result, the impact sound pressure levels $L_{n,eq}$ of a wooden bare floor are computed.

2.3 Suspended ceiling

According to Latvanne [1] and [10], the ΔL_d improvement of the impact sound insulation of a suspended ceiling equals ΔR, if the suspended ceiling is connected resiliently to a bare floor. Thus, it can be assumed that the ceiling boards on the receiving side of the separating floor structure are mostly excited by airborne sound field, because the resilient fixing of the suspended ceiling damps the structural vibration proceeding from the bare floor to the suspended ceiling [1].

The improvement ΔL_d is calculated by comparing the sound reduction index of a bare floor and a floor with a suspended ceiling. Sound reduction indices R in 1/3-octave bands are calculated according to [11-22]. Earlier in [1] it was found that a suspended ceiling with a semi-resilient connection to a bare floor does not improve the impact sound insulation as well as a resiliently connected ceiling. For example, wooden ceiling battens form a strong structural connection between a bare floor and ceiling boards and therefore $\Delta L_d = \Delta R$ is not necessarily valid. [1,10]

2.4 Improvement of additional layers

A lightweight bare floor is hardly sufficient to achieve adequate impact sound insulation and the construction must be improved. The most common methods are adding a floating floor or additional floor boards. These improvements ΔL_{fb} and ΔL_{ff} are calculated according to [1, 10, 23].

At present, there does not seem to be a generally accepted method for calculating the improvement of floating floor on lightweight systems. Hence, the approximations in [10] are used, which mostly originate from the famous derivations by Cremer et al. [24]. Although the wavenumbers in such systems seem to be in sufficient agreement to Cremer's theory [25], the improvements found in practise hardly achieve such high values. In the future, the difference in impact force and injected power to a floating floor on a lightweight floor should be considered.

2.5 Validation

There were two phases in the validation. Firstly, the calculated impact sound pressure level results of the wooden bare floors were validated by comparison with the measured results. This comparison was made for (n = 18) bare floors. There were both joist (n=12 structures) and CLT (n=6 structures) bare floors involved in the validation.

Secondly, the validation of the complete floor structures was carried out for 28 floor constructions. The validation was made only for the floor structures, for which measured 1/3-octave impact sound pressure levels were available. Both laboratory and in-situ measurement data was used in the validation [5, 26-33].

The validation was made by calculating the difference between the measured and calculated impact 1/3-octave band sound pressure levels at a frequency range of 50 to 5000 Hz. The arithmetic mean, the arithmetic mean of the absolute values, the standard deviation, and 95 % confidence interval were calculated for all the differences.

3 Results

3.1 Bare floors

In the bare floor validation, two types of bare floors were studied: joist-plate (n = 9) and massive wood CLT (n = 4) floors. The calculation of $L_{n,eq}$ levels were conducted as described in chapter 2.2. The validation results of bare floor structures are presented in Figure 3.

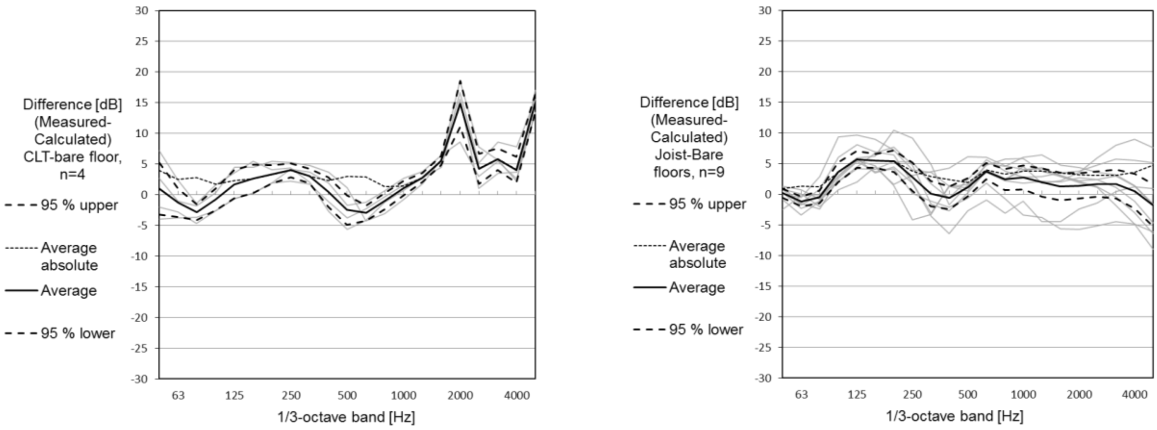

Figure 3: The validation results of the bare floor structures. The validation results of the joist floors types are presented on the left side and CLT results on the right side.

3.2 Complete floor structures

The validation of complete floor structures concerned structures which include at least a bare floor and a suspended ceiling. In addition, most of the complete floor structures consisted of the above-mentioned structural elements and a floating floor or additional floor board layers. Altogether 28 different floor structures were studied in this final validation. For the complete floor structures the validation was made both for the single-number-quantities ($L_{m,w}$ and $L_{n,w}$ + $C_{I,50-2500}$) and for the 1/3-octave band impact sound pressure levels. The validation results of the single-number-quantities are presented in the table 1. The validation results of L_n values are presented in Figure 4.

Table 1: Difference between measured and calculated single-number-quantities

	$L_{n,w}$ [2]	$L_{n,w}$+ $C_{I, 50-2500}$ [2]
Arithmetic mean of the differences [dB]	2 dB	-0,4 dB
Standard deviation of the differences [dB]	7 dB	6 dB
Arithmetic mean of absolute values of the differences [dB]	5 dB	4 dB

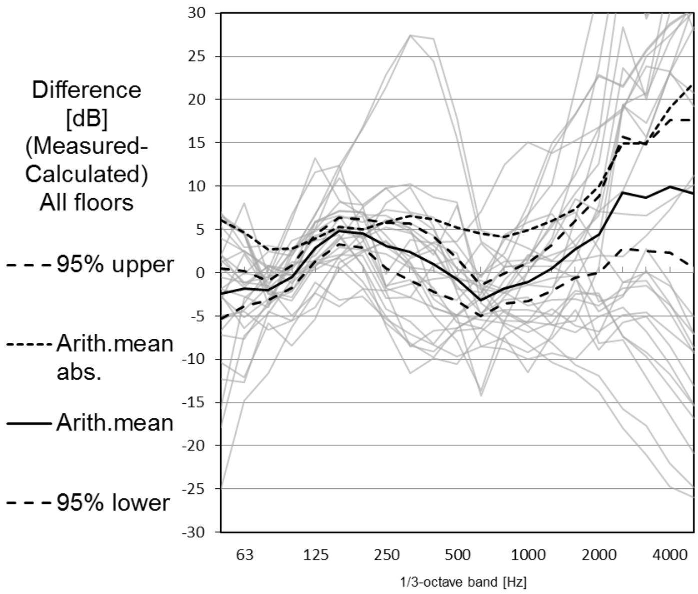

Figure 4: The validation results of the complete floor structures (n=28), including all floor types (CLT and joists)

4 Discussion

The calculated impact sound pressure levels of bare floors were in good accordance throughout the whole frequency range. It was found that the results of CLT bare floors were highly dependent on the starting values of the calculation. In order to get as realistic calculation results as possible, the starting values should be chosen carefully. The problem is that wood, as a natural product with its orthotropic characteristics can contain a lot of calculation uncertainties. In complete structures, there can also be variation in the dimensions and boundary conditions dealing with the vibrational behaviour of the floors. [1]

The validation indicated that the impact sound pressure levels, calculated by the presented engineering method, are in best accordance with measurements at a frequency range of 50 to 1000 Hz. The calculation uncertainty depends on the number of structural layers of the floor. The more complicated the floor becomes; the more uncertainty occurs.

Based on the validation data, it can be said that the calculation uncertainty rises at a frequency range of over 1000 Hz. One of the challenges of the method and accuracy is the combination of structural layers. Adding more layers also affects the acoustical performance of the existing layers. The best results were achieved in the calculation of simple joist and CLT floors. It was noticed that the present calculation underestimates the improvement in impact sound pressure levels of additional boards. Possible energy losses occurring on the boundaries of different structural layers are also not considered.

The validation also showed, that the present calculation [10] overestimates the improvement in impact sound pressure levels of floating floors. It was also found that the improvement of impact sound pressure levels given by the floor coverings is strongly dependent on the structural layer underneath the covering. The effect of the floor coverings has been studied earlier in references [1, 30, 31, 34]. More extensive data on the performance of floor coverings installed on different wooden layers and boards is required, in order to develop the calculation method further. The lack of this data is the most critical obstacle in developing exact calculation methods for the impact sound insulation of wooden floors. The calculation method is still in the process of development and the acoustical department of AINS Group Ltd is continuously studying the possibilities to improve the accuracy of the method.

5 Summary

The object of this paper was to validate the results of the developed engineering method for the calculation of impact sound insulation of wooden floors. The calculation is carried out in four phases: the initial phase, additional layers, summation and derivation of single-number quantities. In this study, the calculation results of wooden bare floors and complete wooden floors were validated with comparisons to measurement results presented in the research literature and the measurement database of the acoustical department of AINS Group Ltd.

The validated structures consisted of 13 wooden bare floors and 28 complete wooden floors. Based on the validation, the developed engineering method is most accurate in the calculation of impact sound insulation at frequencies from 50 to 1000 Hz. The difference between measured and calculated impact sound pressure levels varies from -5 dB to +5 dB.

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