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Design possibilities for impact noise insulation in lightweight floors – A parameter study

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A theoretical prediction model for impact noise of lightweight floors has been developed by the authors. The prediction model has been presented in a thesis and in papers, including a description of the ISO tapping machine acting on lightweight floors. A brief description of the model will be given. The model is herein used in a parameter study. These results, in conjunction with empirical results, are used to make some statements concerning favorable choices and design possibilities for impact noise insulation in lightweight floor structures. Some aspects of the validity of the prediction model are discussed, and e.g. the influence of mineral wool in the cavity is examined.

1. INTRODUCTION

The development of new building systems has intensified. Such building systems are often lightweight, and developed to be used in load-bearing structures and dwellings. Although this sort of systems often have many advantages – particularly that of low weight – they often fail to provide adequate sound insulation. In order to find out which of the parameters of a lightweight floor that are important to yield an adequate sound insulation, and how to change them in order to achieve better results, the prediction model in [1] and the simple mass-resistance excitation model in [2] is used in a parameter study. It should be noted that the parameter study only applies for the type of floor structure included there and not necessarily for e.g. a floor with resilient channels. However, the prediction model is first briefly described.

2. THE PREDICTION MODEL

The prediction model in [1] is a deterministic mathematical model starting from differential equations. The floor structure examined is consisting of two plates rigidly connected and stiffened by beams. A periodical description of the structure is used, the coupled plate equations obtained are Fourier transformed and solved for the transformed deformation. The excitation force caused by the ISO-tapping machine when applied to lightweight floors was derived in [2]. A lumped model of the impact of the hammer in a floor is used. The floor is modelled by a resilient part and an energy consuming part, represented by a spring with stiffness and by a dashpot with resistance respectively. The physical meaning of the two components is that the resilient part is due to local deformation of the plate and the resistive part to energy transportation within the plate. The radiated power is obtained by use of integral methods, using the transformed displacement. The impact sound level is calculated from the radiated power, a diffuse sound field in the receiver room being assumed.

In order to find out which of the parameters of a lightweight floor that are important and how to change them in order to achieve better results, the prediction model in [1,2] is used in a parameter study. It should therefore be noted that the parameter study only applies for the type of floor structure included there; i.e., a structure consisting of two plates rigidly connected to the reinforcing beams ($w_1(nl) = w_f = w_2(nl)$). The floor structure can be seen in Figure 1. Thus, the results found here cannot automatically be applied to another type of floor structure, such as a floor with resilient channels. The variations are based on a original set of input data (in what is called the base floor). One parameter is varied at the time. The variation is performed with a factor taking the values $\chi=\{0.25\ 0.5\ 1\ 2\ 4\}$ applied to the varied parameter, keeping the rest of the parameters constant. The result is presented as the increase in impact sound level compared to the base floor, $\Delta L_n = L_n - L_n|_0$, where the notation $\cdot|_0$ denotes the base floor and the original set of data. In the figures this variation will be represented by five curves of ΔL_n (including the zero line).

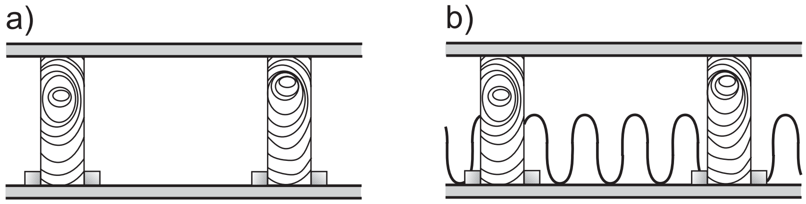

Figure 1. *A sketch of the base floor structure. Case a) without mineral wool, case b) with mineral wool.*

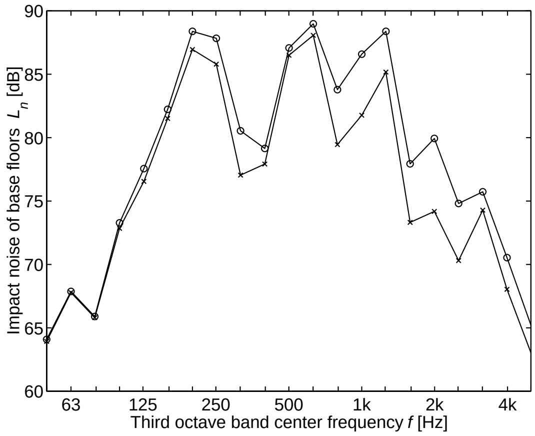

Figure 2. *Impact noise level of the base floors, case a) without mineral wool (–o–), case b) with mineral wool (–×–).*

A sketch of the floor structure can be seen in Figure 1, and the results for the calculations of the base floor are shown in 2, where the case without mineral wool in the cavity is denoted (–o–), and the case with mineral wool of a depth of half the cavity depth is denoted (–×–). The base floor without mineral wool is used except where the opposite is noted. Some of the variations will just change the positions of the peaks and dips, but other variations will cause a broadband increase or decrease of the impact sound level. Some extra variations can be found in [3].

3. THE PARAMETER STUDY

The material and geometrical data of the original configuration are: 'plate' modulus for the wood in the plates $E/(1-\nu^2) = 6 \cdot 10^9$ N/m^2, thickness of the (solid wood) plates $22 \cdot 10^{-3}$ m. The masses per unit area of the plates are $m''_1 = m''_2 = 10$ kg/m^2. The beams have Young's modulus $E_f = 11 \cdot 10^9$ N/m^2 and density $\rho_f = 455$ kg/m^3 and cross section 67 × 220 mm, giving an area of $A_f = 14.7 \cdot 10^{-3}$

m^2 and a moment of inertia of I_f=5.95 · 10^{-5} m^4. The material damping for wood is η=0.03, added to the Young's modulus in the plates and beams. The depth of the cavity d=220 · 10^{-3} m – the same as the height of the beams. When mineral wool is present, the flow resistivity is R=11770 Ns/m^4. The density of the air is ρ = 1.29 kg/m^3 and the speed of sound in air is c=340 m/s. Material damping for the air is taken to be ρ_{air} = 10^{-8}, added to the speed of sound. Only one excitation position is used: x_0=0.43 m. The line order is o, ×, the zero line without marker, □ and ∇ when not said differently. The corresponding variation factor is χ={0.25 0.5 1 2 4}.

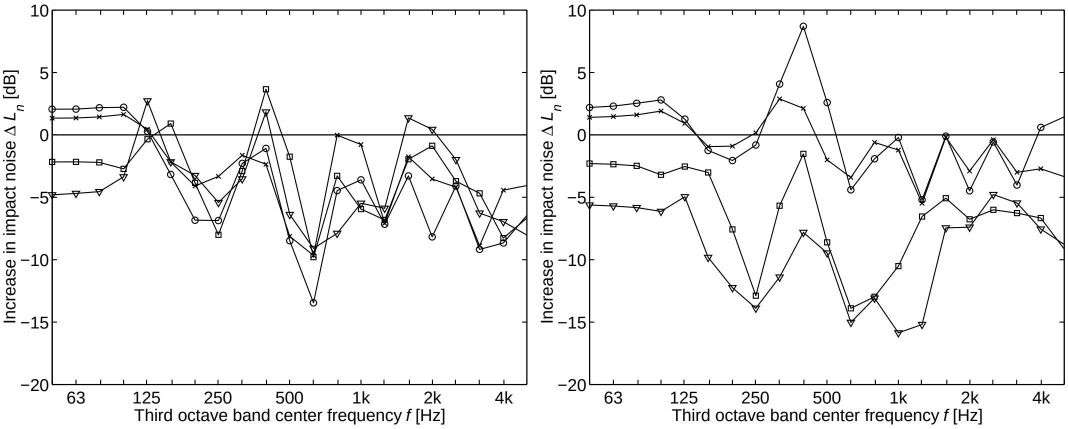

Figure 3. *Increase in impact noise level when varying the weight of the plates. Left: The weight of the first plate is varied as* $m''_1 = \chi \cdot m''_1|_0$. *Right: The weight of the second plate is varied as* $m''_2 = \chi \cdot m''_2|_0$.

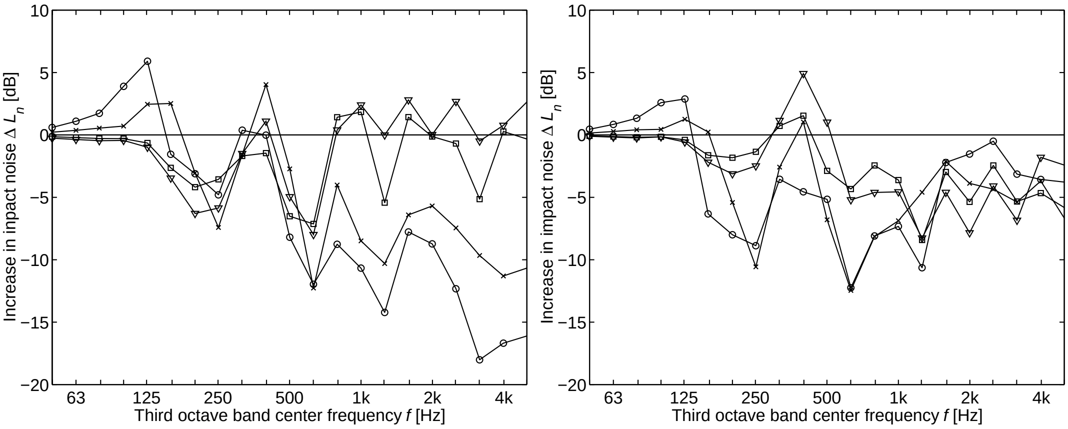

Figure 4. *Increase in impact noise level when varying the stiffness of the plates. Left: The stiffness of the first plate is varied as* $B'_1 = \chi \cdot B'_1|_0$. *Right: The stiffness of the second plate is varied as* $B'_2 = \chi \cdot B'_2|_0$.

First, in Figure 3, the weight of the plates is varied. It can be seen that increasing the weight of the second plate decreases the impact sound more than the increase for the first plate. It should be remembered here that changes in the first plate affect both the system (that is the wave transmission through the floor structure) and the excitation force as the excitation model in [2] is used. The stiffnesses of the plates are then varied, Figure 4. In this case, a decrease the stiffness of the first plate is advantageous. The reason for this is that a softer excitation point will influence the excitation force in a favourable manner, extending the contact time. The influence of the beams is analysed in Figure 5. No big changes can be seen, but at lower frequencies (below 250 Hz) positive effects can be gained. The beams should be weaker and heavier in order to decrease the impact sound in this frequency range.

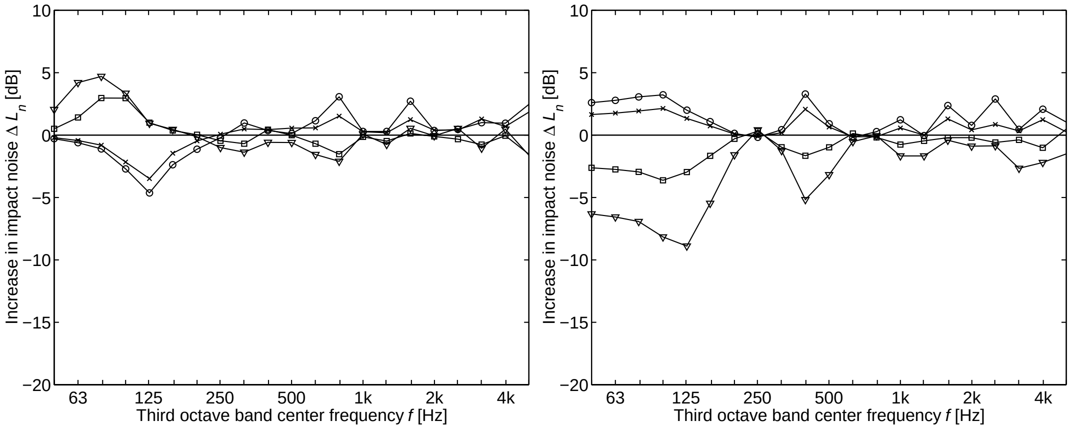

Figure 5. *Increase in impact noise level when varying the beams. Left: The stiffness is varied as* $E_f = \chi \cdot E_f|_0$*. Right: The weight is varied as* $\rho_f = \chi \cdot \rho_f|_0$*..*

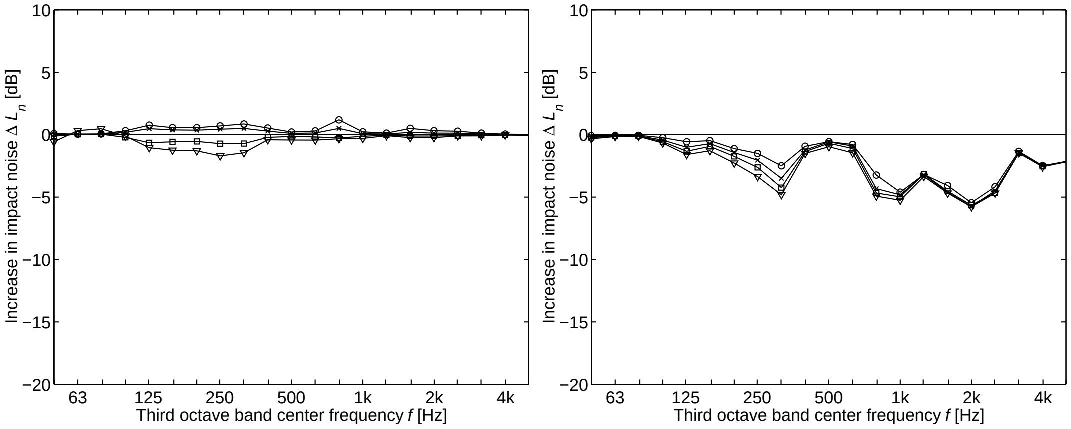

Figure 6. *Increase in impact noise level when varying the mineral wool. Left: The flow Resistance is varied as* $R=\chi \cdot R|_0$ *with the ordinal line order. The case b) in Figures 1 and 2 is used as base floor. Right: The fraction is varied as* $d_{min} = \{0\ 0.25\ 0.5\ 0.75\ 1\} \cdot d$ *with the line order: the zero line without marker, o, ×, □and ∇.*

The influence of mineral wool was also studied. In Figure 6 left the flow resistance of the mineral wool is varied (the case b in Figures 1 and 2), and in Figure 6 right the fraction of mineral wool occupying the cavity is varied. Changing the flow resistance does not affect the result much, but the result is clear. The result of the variation can especially be noticed in the frequency region 100–316 Hz, and increasing the flow resistance decreases the impact noise in this region. However, this result is probably in part due to the limitation of the description of the mineral wool in the prediction model. The mineral wool is described by a version of the Delaney and Bazely model [4], in which the structural phase of the medium is included only as second order effects, as the empirical model only has a fluid phase. However, with increasing flow resistance the structural phase will eventually be increasingly important, implying that in reality there should be an optimal value for the flow resistance. In order to improve the model, the mineral wool should be modeled as a Biot material [5], that includes both structural and fluid phases. In the case of varying the fraction of mineral wool, Figure 6 right, a big difference can be seen whether mineral wool is present or not. When mineral wool is present, increasing the fraction will not make any major difference, but in the frequency region 100–316 Hz it can be seen that increasing the fraction decreases the impact noise.

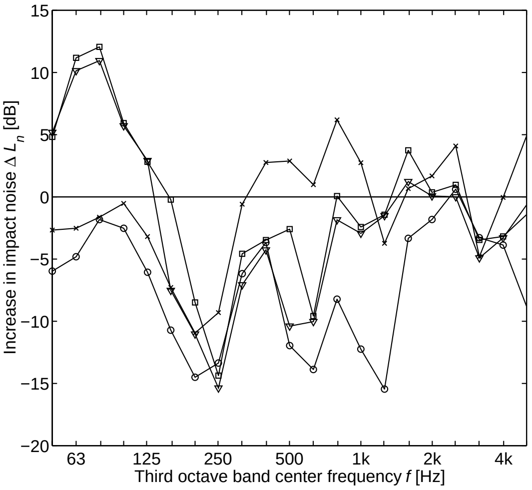

***Figure** 7. Increase in impact noise level when varying the distance between the beams. The distance is varied as $L=\chi\cdot L|_0$.*

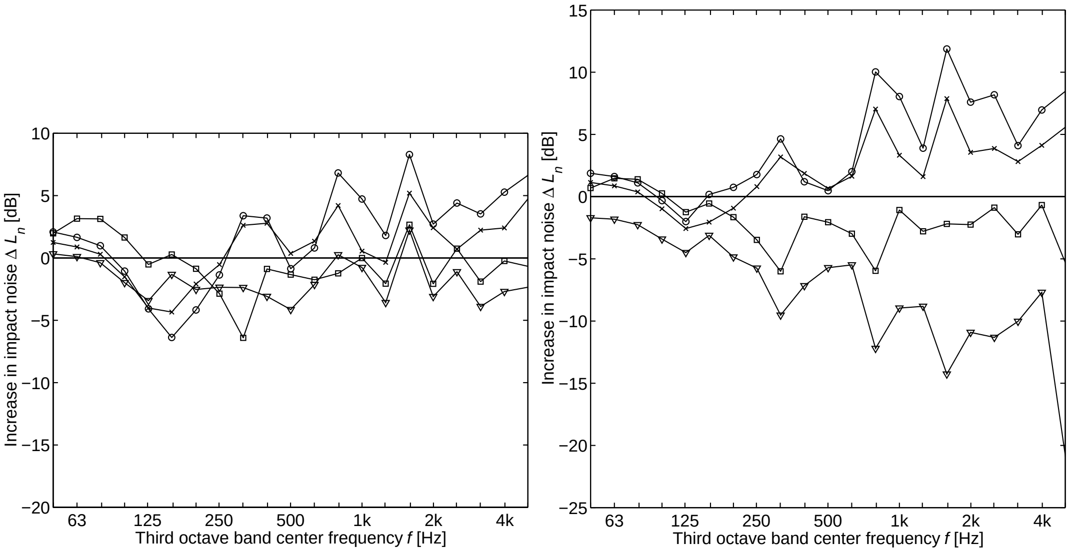

***Figure 8**. Increase in impact noise level when varying the depth of the construction, including both cavity and beams. The depth is varied as $d=\chi\cdot d|_0$. Left: No mineral wool in the cavity, case a. Right: The cavity contains mineral wool of a height of 11 cm, case b.*

The periodic distance between the beams is varied in Figure 7. The influence seen is mainly due to frequency shifts of the peaks and dips. However, at low frequencies, below 125 Hz, the results indicate that increasing the periodic distance increases the impact noise level. The main reason for this is probably the decrease in weight associated with the increase of periodic distance. The tendency in these results is confirmed by measurements found in [6] (also reported and discussed in [7]), where the spacing is changed from 400 mm to 600 mm in a floor structure similar to the one studied herein. For low frequencies, the floor with a 400 mm spacing had lower impact noise level than the floor with 600 mm spacing. However, for other frequencies the results shift. In connection with this, it may be interesting to note that for another floor structure studied in [7, pp. 40–43], a floor structure with a resilient channel, a clear trend could be seen in the measurement; the floor with 400 mm spacing had lower impact noise level than the floor with 600 mm spacing in the entire frequency range.

In Figure 8 is the variation of the construction depth studied. Both the depth of the cavity and the beams are varied. In Figure 8 left no mineral wool is included in the cavity (case a in Figures 1 and 2), whereas in Figure 8 right mineral wool is included in the cavity (case b). In this case it makes a major difference if mineral wool is present or not; without mineral wool, increasing the construction depth do decrease the impact noise, but if mineral wool is present the decrees can be up to 10 – 15 dB larger than if mineral wool is not present. The difference is more predominant for higher frequencies than for lower frequencies.

4. CONCLUSIONS

The largest positive effects (that is, decreasing the impact sound level) are gained by: increasing the construction depth (when mineral wool is present), increasing the mass of the second plate (without changing the stiffness, which can be achieved if adding an extra plate loosely to the first one), or for low frequencies increasing the mass and decreasing the stiffness of the beams. Other variations also have a large influence in a limited frequency range, but this influence is mainly due to frequency shifts of the peaks and dips in the impact noise frequency curve.

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