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IMPACT SOUND INSULATION OF LIGHTWEIGHT TIMBER BASED FLOATING FLOORS: MEASUREMENT AND PREDICTION

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1 INTRODUCTION

This paper describes research into the performance of lightweight timber based floating floors having open cell polyurethane foam resilient layers and comprising relatively small sections joined together. Such flooring systems were first developed by Mackenzie[1] and the results presented here were obtained from measurements on sections of flooring comprising 9 mm medium density fibreboard (mdf) having a nominally 8 mm thick recycled polyurethane foam (rebond) resilient layer.

The use of rebond in floating floors and its performance under compressive stress has been described[2], as has a method for predicting the improvement in impact sound insulation (ΔL) when sections of such lightweight floating floors are placed on concrete supporting floors[3]. The prediction of ΔL was achieved using the results of laboratory measurements of the dynamic stiffness of the material comprising the resilient layer. These measurements first were conducted according to the method described in BS EN 29052-1[4]. Later, this method was modified to include the stiffness of the air contained in the foam specimens.

2 PREDICTION OF ΔL

EN 12354-2[5] contains equations for the prediction of the improvement in impact sound insulation (ΔL) derived from the addition of asphalt or dry construction floating floors (highly damped) and sand/cement screeds (lightly damped).

Asphalt or dry construction floating floor

$$\Delta L = 40\lg\left(\frac{f}{f_r}\right) \quad \text{dB}$$

Equation 1

Sand/cement screed

$$\Delta L = 30\lg\left(\frac{f}{f_r}\right) \quad \text{dB}$$

Equation 2

where f and f_r are the excitation frequency and the floating floor mass-spring frequency respectively. Equation 1 was derived by Cremer and was modified for lightweight wooden floating floors[6]. The modification is necessary because the mass of the tapping machine hammers becomes significant above a certain cut off frequency (f_{co}) for all floors. With lightweight floating floors f_{co} lies within the frequency range of interest to building acoustics and must be accounted for. Therefore, Equation 1 becomes[6]

$$\Delta L = 40\lg\left(\frac{f}{f_r}\right) + 10\lg\left(1+\left(\frac{f}{f_{co}}\right)^2\right) \text{ dB}$$

Equation 3

where f_{co} is given by:

$$f_{co} = \frac{Z}{2\pi m_o} \quad \text{Hz}$$

Equation 4

and $Z = 2.3 c_L \rho h^2 \quad \text{Ns/m}$

Equation 5

where c_L, ρ and h are the longitudinal wavespeed in the mdf, its density and thickness respectively. Z is the driving point impedance of an infinite plate.

Floating floors can be described as locally or resonantly reacting[7]. A locally reacting floating floor is one where the force due to an impact on the floating surface is mainly transmitted to the supporting floor mainly in the immediate vicinity of the excitation. In contrast, the most significant source of force transmission to the supporting floor with a resonantly reacting floating floor is due to a more or less homogeneous bending wave field on the floating slab[7]. Equation 1 and Equation 3 assume that the floating floor is infinite and therefore there are no reflections from its edges. A highly damped floor approximates this situation because any reflections are insignificant and Equation 3 was used to predict ΔL in the earlier publications based on this research[3,9]. This paper presents the results of measurements that justify the proposition that the lightweight mdf floating flooring can be justifiably treated as locally reacting.

3 EXPERIMENTAL APPROACH

Tests were conducted on individual sections of lightweight floating flooring and larger areas of floating floor formed by slotting the tongued and grooved sections together. In order to decide whether such floors are locally or resonantly reacting, it had to be determined whether the sections of floating floor behaved like pistons or whether they supported modes associated with a reverberant field. It was also necessary to determine whether this behaviour was modified when the sections of flooring were connected to others. This was achieved through the measurement of the driving point mobility of flooring sections using single sections of floating flooring and on six sections connected together. Measurements of impact sound insulation were also conducted on a concrete supporting floor with individual sections and with a larger area of floating flooring.

4 DRIVING POINT MOBILITY

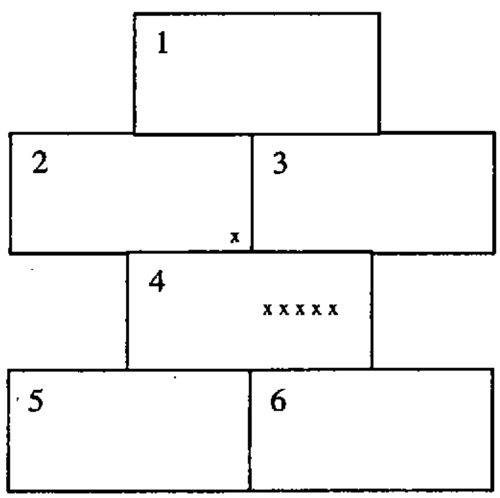
Equation 5 gives the driving point impedance (Z) for an infinite plate. Measurement of the driving point mobility (Y) of the mdf flooring using a force hammer would allow comparison with that of an infinite plate comprising the same thickness of mdf since:

$$Y = \frac{1}{Z} \quad \text{m/Ns}$$

Equation 6

In addition, such measurements would show whether the sections of flooring supported bending wave modes and whether their behaviour was modified when fastened to others. The driving point mobility was measured therefore.

Six 1.2 m x 0.6 m sections of floor were arranged on a concrete supporting floor as indicated in Figure 1. Mobility was measured using a force hammer comprising a Bruel and Kjaer type 8200 force transducer. A Bruel and Kjaer type 4333 accelerometer, two Bruel and Kjaer type 2615 charge amplifiers and an Ono Sokki type 360 dual channel analyser were also used. Measurements were made in the corner of board 2 (2 cm from boards 2 and 4) and at 100 mm intervals from the centre of board 4 up to 500 mm. In all, 9 measurements were made with the group of six boards including three taken in the centre of board 4. Measurements were taken on two different single sections of board at their centres and 100 mm from their centres.



Measurement positions indicated by x

Figure 1; arrangement of floating floor sections for mobility tests.

5 DRIVING POINT MOBILITY MEASUREMENTS RESULTS

The results of the measurements of the driving point mobility (*Y*) are illustrated in Figure 2. Below 100 Hz it can be seen that the mobility peaks occur at the same frequencies (55 Hz and 95 Hz) although the magnitude of the peaks in the mobility is reduced when the boards are attached to others. Between 100 Hz and 1000 Hz the peaks in the mobility again, for the most part, occur at the same frequency or are within 5 Hz of each other. Between 200 Hz and 500 Hz, *Y* is 2.73×10^{-3} m/Ns and 2.72×10^{-3} m/Ns respectively for the group of six sections fixed together and the single section of flooring compared with the infinite plate mobility of 2.83×10^{-3} m/Ns. Above 2000 Hz, the small peaks superimposed on the general trends of the two curves begin to occur at different frequencies but the general trend is that the mobilities are roughly the same apart from a minimum in the single board mobility between 1400 Hz and 1500 Hz. However, as the width of the third octave bands increases with frequency, small differences in the frequencies at which the peaks in mobility occur become increasingly less significant.

The mdf sections of flooring clearly exhibit modal behaviour in the frequency range from 35 Hz to 2000 Hz. However, it appeared that their response to the excitation differed little whether or not single boards or groups of boards fixed together were tested.

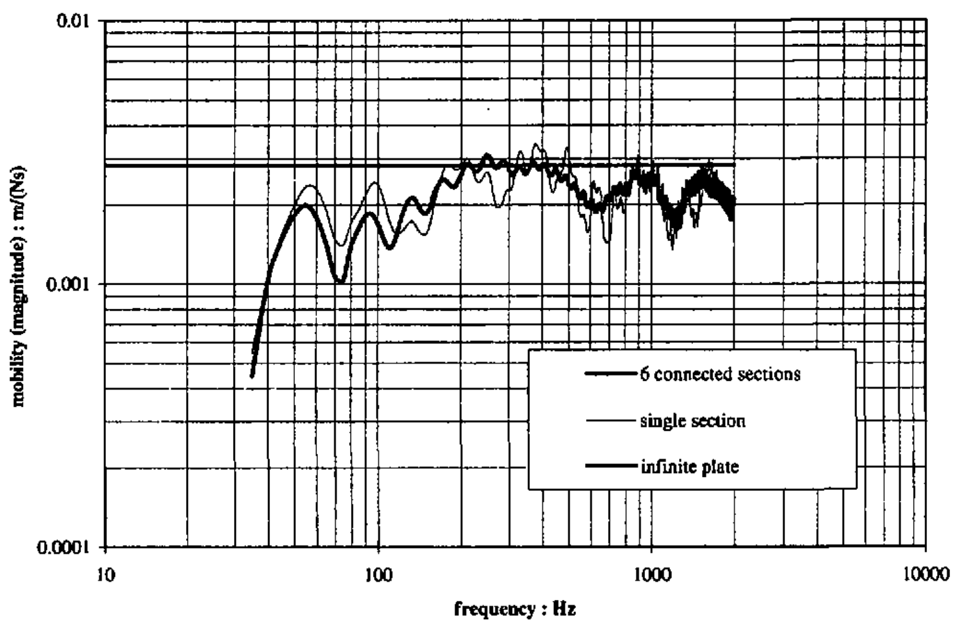


Figure 2; **average driving point mobility for single sections of flooring and for sections attached to others.**

6 IMPACT SOUND INSULATION MEASUREMENTS

The field measurements of impact sound pressure level were carried out using the mdf floating floor and two rooms vertically separated by a concrete floor. Eight sections of floating floor were fitted together on the supporting floor and the impact sound pressure level in the room below measured according to the method described in ISO 140-7[8]. The arrangement of the flooring sections is illustrated in Figure 3. The total area of floating floor comprising the connected sections was 5.8 m^2. Four measurements were made with the tapping machine across joints, another five were made with the machine in the centre of the boards. These results were then averaged to give the measured L'_{nT}. Four tapping machine positions were used on the bare floor prior to laying the floating floor. The ceiling of the receiving room was 12.6 m^2 in area. The floor of the source room had an area of 19 m^2. Both rooms had identical width (3.6 m) but the source room was longer (5.3 m c.f. 3.5 m). The measurements were carried out on the portion of separating floor directly above the receiving room.

Measurements were then conducted using single sections of flooring in the same positions on the separating floor that had been occupied by the individual sections comprising the 5.8 m^2 area of flooring. (The positions of the flooring sections comprising the large area of flooring had been marked on the separating floor.) Measurement of impact sound insulation was conducted with the tapping machine in three of these positions. The tapping machine was placed in the centre of the flooring section or in the centre of the rectangle that would be covered by the flooring section. Three different sections of floor were used and in each position, measurements were taken on the bare floor, on the section of floating floor and on the section of floating floor with its edges completely sealed with petroleum jelly. A thick fillet of petroleum jelly was applied to all four edges of the boards in order to prevent air movement in and out of the resilient layer beneath the mdf. The petroleum jelly was particularly thick on the two tongued edges where the void between the edge of the resilient layer and the edge of the mdf was completely filled.

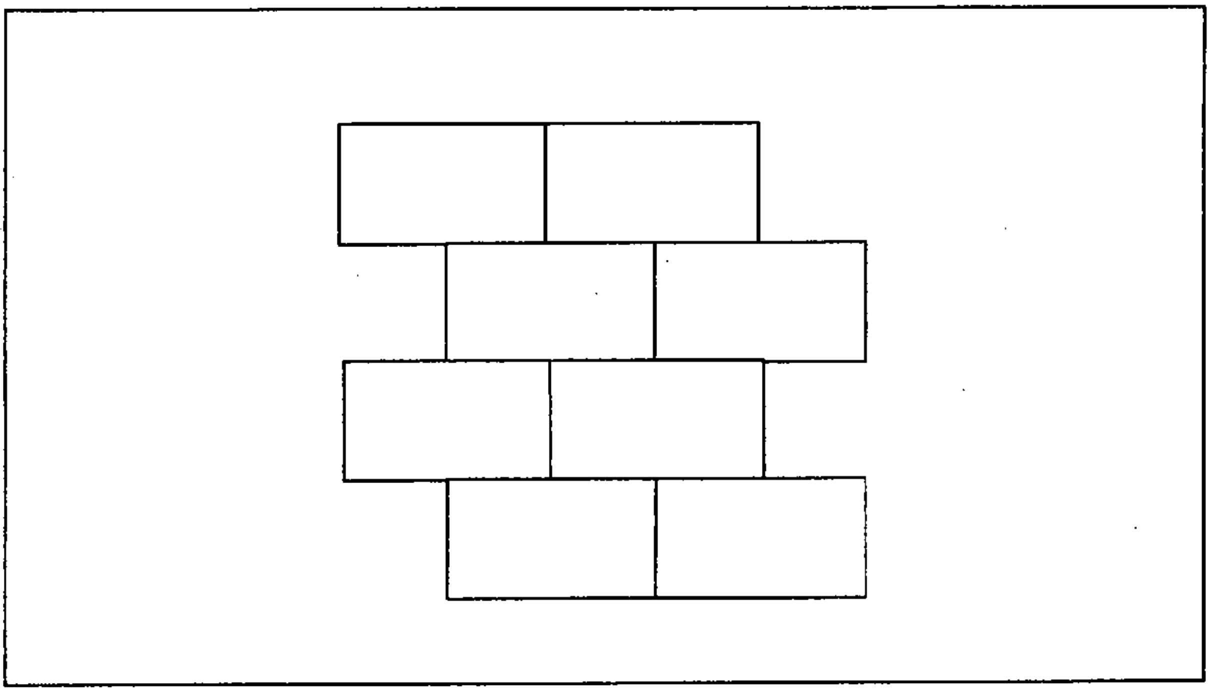


Figure 3; arrangement of flooring sections for impact sound insulation test.

7 IMPACT SOUND INSULATION MEASUREMENT RESULTS

Figure 5 shows the comparison of the improvement in ΔL from the different impact sound insulation measurements described. $L'_{nT,w}$ was 47 dB for all three sets of measurements on the floating flooring.

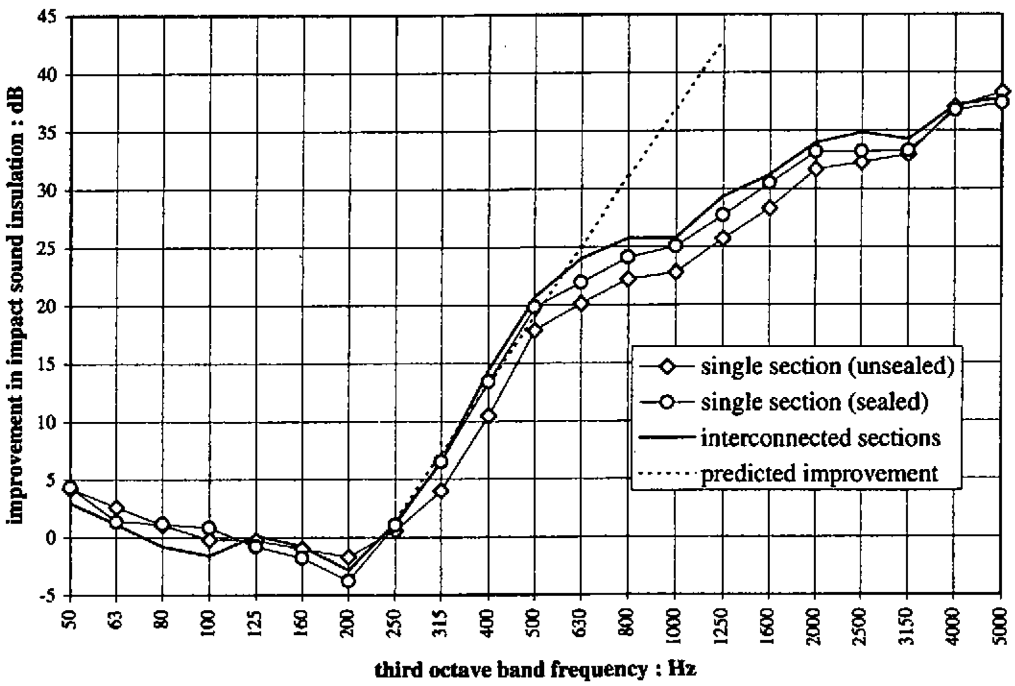


Figure 4; ΔL with single sections and larger section of floating floor.

8 DISCUSSION

The results of the mobility measurements show that the eigenfrequencies of the sections of flooring were mostly unchanged when the individual sections were connected to others. This was particularly the case below 100 Hz. However, the reduced height of the mobility peaks below 100 Hz when the sections of flooring are fixed together compared with the results for the single sections, suggests that there is more damping in this circumstance. It is likely that some of the energy is transmitted across the joints rather than being reflected back from the edges of the flooring boards thus increasing the losses in the sections attached to others.

In the frequency range between 100 Hz and 1000 Hz the relationship between the two curves shown in Figure 2 becomes more complicated. All but a few peaks occur at the same frequency but here the curves cross and the flooring section attached to others exhibits higher mobility than the single boards at some frequencies. However, the close similarity between the average mobilities and the infinite plate mobility in this frequency range is significant. Between 200 Hz and 500 Hz, the measured average mobilities and that of an infinite plate of the same material and thickness are very close. Importantly, $L'_{nT,w}$ is determined by the performance of the lightweight floating floor in the frequency range from 100 Hz to 500 Hz.

The impact sound measurements also show close similarity between the results from the large section of flooring and the individual sections. Figure 4 shows that sealing the edges of the single sections resulted in performance closer to that of the large section between 250 Hz and 500 Hz although the performance at the resonance was made worse. It is clear that any increase in the stiffness of the resilient layer, due to the air contained in it being prevented from moving laterally out of the foam, was insufficient to move the resonance frequency to a higher third octave band. However, preventing air movement through the foam may have reduced the damping in the resilient layer resulting in the worse performance at the resonance. The improved performance above the resonance may be due to the thick fillet of petroleum jelly sealant damping the edges of the mdf floating surface. However, it is not known whether sealing the edges of the individual sections of flooring will result in performance closer to that of large areas of flooring, or complete floating floors, in all situations. Together, the results of the mobility measurements and the impact sound level measurements suggest that the performance of these lightweight floating floors is governed by the performance of the individual sections comprising the floor.

The good correlation between the measured mobility of the flooring and that calculated for an infinite plate illustrated in Figure 2 suggests that it may be possible to use Equation 3 to predict ΔL for complete mdf floating floors. The curve in Figure 4, showing the predicted values of ΔL, was obtained using Equation 3 and by projecting the curve generated onto the $\Delta L = 0$ dB horizontal axis[3]. However, it should be noted that the use of Equation 3 is only justified for frequencies above the mass-spring resonance frequency of the floating floor.

It is of note that the cut off frequency of the mdf used in the flooring occurs at 112 Hz and therefore lies below the mass-spring frequency of the lightweight floating floor. The mass-spring frequency was calculated to be 355 Hz from knowledge of the mass of the mdf sections and the dynamic stiffness of the resilient layer using:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{s'}{m'}} \quad \text{Hz where:}$$

s' = dynamic stiffness per unit area of the foam (35.4 MN/m^3);
m' = mass per unit area of the mdf (7.1 kg/m^2).

Figure 4 shows that the resonance for single flooring sections and those fixed together lies in the 200 Hz third octave frequency band. The calculated resonance frequency of 355 Hz lies on the cusp between the 250 Hz and the 315 Hz third octave bands. However, when the mass of the tapping machine (10.3 kg) is added to that of the mdf, the resonance frequency of the lumped mass-spring system comprising a single section of flooring (surface area = 1.2 m x 0.6 m) and the tapping machine is found to be 205 Hz. It may be that the improvement in ΔL between the 200 Hz and the 400 Hz third octave bands is dependent upon the tapping machine. A combination of its additional mass, reducing the resonance frequency and the reduced force input due to the significance of the mass impedance of the hammers compared with that of the mdf.

That the resonance frequency of larger area of flooring occurs in the 200 Hz third octave band is further evidence that the performance of this type of floor is determined by the performance of individual sections of which the floor is comprised. Few measurements have been conducted on complete lightweight floating floor systems as part of this research but good correlation has been found between predicted and calculated ΔL and $L'_{nT,w}$ with the results available[9]. Further research using full size lightweight floating floor systems is necessary before any firm conclusions can be made

9 CONCLUSIONS

The results presented in this paper support the argument that the performance of the lightweight shallow profile tongued and grooved floors is governed by the performance of their individual sections. This suggests that such floors can be described as locally reacting and that their contribution to the improvement of the impact sound insulation of concrete supporting floors can justifiably be calculated using Cremer's equation, modified to account for the mass of the tapping machine hammers. However, the improvement in ΔL below the calculated resonance frequency of the flooring system may be due to the choice of impact source, the standard tapping machine.

The results also suggest that impact sound insulation measurements using single sections of such flooring give a realistic indication of the performance of complete floating floor systems. If further experimentation could confirm this, then product development might become easier and less expensive.

10 REFERENCES

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