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Prediction on the Enhancement of the Impact Sound Insulation to a Floating Floor with Resilient Interlayer

Xianfeng Huang[1, 2, 3], Yao Meng [1, 2, 3] and Riming Huang [1, 2, 3]

[1] College of Civil Engineering and Architecture, Guangxi University, Nanning 530004.

[2] Guangxi Key Laboratory of Disaster Prevention and Engineering Safety, Guangxi University, Nanning 530004.

[3] Key Laboratory of Disaster Prevention and Structural Safety of Ministry of Education, Guangxi University, Nanning 530004.

[a] Email: seulee@163.coml, [b]Email: 1148500367@qq.com, [c]Email: 1729753937@qq.com.

Abstract. This paper describes a theoretical method for predicting the improvement of the impact sound insulation to a floating floor with the resilient interlayer. Statistical energy analysis (SEA) model, which is skilful in calculating the floor impact sound, is set up for calculating the reduction in impact sound pressure level in downstairs room. The sound transmission paths which include direct path and flanking paths are analyzed to find the dominant one; the factors that affect impact sound reduction for a floating floor are explored. Then, the impact sound level in downstairs room is determined and comparisons between predicted and measured data are conducted. It is indicated that for the impact sound transmission across a floating floor, the flanking path impact sound level contribute tiny influence on overall sound level in downstairs room, and a floating floor with low stiffness interlayer exhibits favorable sound insulation on direct path. The SEA approach applies to the floating floors with resilient interlayers, which are experimentally verified, provides a guidance in sound insulation design.

1. Introduction

The floating floor is usually adopted in a building to achieve higher impact sound insulation, since the resilient interlayer in the floating floor can reduce the sound transmission effectively. The commonly used resilient materials include rubber mat, mineral wool and foam etc. The performance of the resilient material against impact sound is related to the dynamic stiffness (stiffness coefficient) of the interlayer. Kim[1] studied 51 groups of resilient interlayers to investigate the relationship between the impact sound insulation and its dynamic stiffness, it was found that the dynamic stiffness reduced with the increase of resilient interlayer thickness, the impact sound insulation improvement increased as dynamic stiffness reduced, and it is also related to frequency. Based on ISO140-8 international regulations, Schiavi[2] analyzed the comparison between the measured data and the predicted data and indicated that the dynamic stiffness was positively correlated with the preloading of the floating floor. P Mees.[3] studied the topic of installing resilient interlayer between wall and floor, and analyzed the sound attenuation pattern of the structural sound excited on a wall and transmitted to a floor across a resilient interlayer. Based on the EN-12345-2, Craik[4] analyzed the direct and flanking sound transmission from the upstairs room to downstairs rooms which separated by a floating floor, and used SEA method to predict the impact sound pressure level in a receiving room, and investigated to optimized the stiffness material type and thickness of the interlayer in a floating floor structure with the enhancement of impact sound insulation. All above researches provide inspirations to the study in this paper to explore the patterns which the enhancement of impact sound insulation varies with the properties of a resilient interlayer.

2. SEA Prediction Model

A floating floor refers to a concrete slab floor with a resilient interlayer to isolate impact sound, and then a face-layer is set on the top of the resilient interlayer，as shown in Figure 1. In accordance with the requirements of the code, standard tapping machine was used to strike a floating floor, then the impact sound pressure levels were measured in room 5 underneath the floor. Sound energy is generated by tapping machine on the floor 2 to cause the impact sound transmission through two paths: 2-3-4-5 and 2-3-4-6-5, one is direct transmission path, the other are flanking transmission paths which include 4 paths due to four side walls[4].

Impact sound transmission across a floor involves a direct transmission path, which the impact sound transmitted from an up-stair room into the down-stair room directly; and four flanking transmission paths, which impact sound passed from floor through each of the side walls, and to the down-stair rooms finally, which is only considered the first-order flanking sound transmission. Sound transmission would be encountered in the process of T junction, and the transmission loss will be occurred, this is sound coupling within a T junction. two paths are considered: direct path: Floor 2 - resilient interlayer 3 - concrete slab 4 - room 5; flanking path: Floor 2 - resilient interlayer 3 - concrete slab 4 - wall 6- room 5.

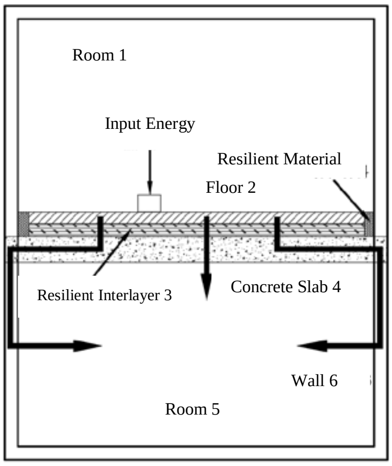

Figure 1. The floating floor system

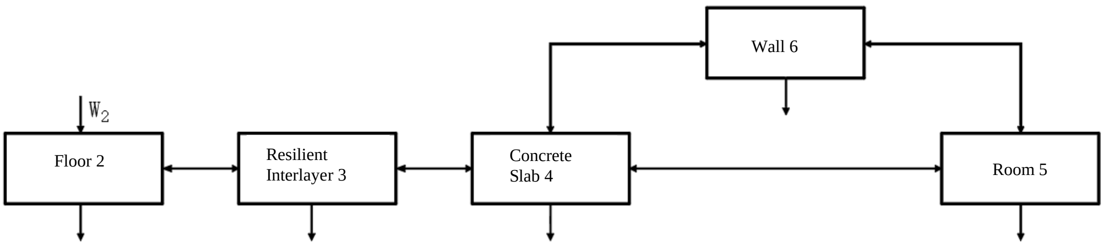

Figure 2. The SEA model of a floating floor

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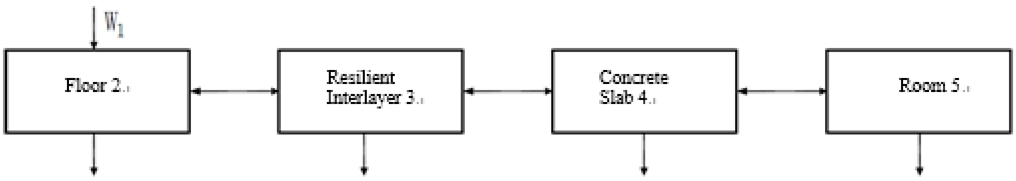

Figure 3. The direct path

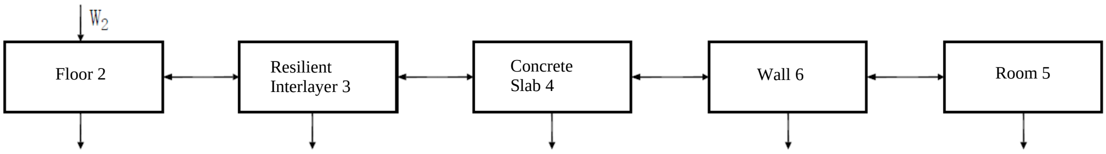

Figure 4. The flanking path

The above model ignored the sound energy inverse flows from the resilient interlayer, and since subsystems 3, 4, 6, and 5 have very few input sound energy, the sound energy returned from the subsystem and the sound energy input subsystems 3, 4, 6, and 5 could be ignore, therefore, the sound energy balance equation of the model can be written as:

$$\begin{bmatrix} -\eta_2 & & & & \\ \eta_{23} & -\eta_3 & & & \\ & \eta_{34} & -\eta_4 & & \\ & & \eta_{46} & -\eta_6 & \\ & & & \eta_{65} & -\eta_5 \end{bmatrix} \begin{bmatrix} E_2 \\ E_3 \\ E_4 \\ E_6 \\ E_5 \end{bmatrix} = \begin{bmatrix} -W_2/\omega \\ \\ \\ \\ \\ \end{bmatrix} \tag{1}$$

Where η_i is the internal loss factor, η_{ij} is the coupling loss factor , E_i is the energy of each subsystem and W_2 is the energy input subsystems 2.

Based on equation (1), the impact sound insulation can be obtained, the impact sound level on the direct path is:

$$L_{p,direct} = 10\log(\frac{p^2}{p_0^2}) = 10\log\frac{W_2\eta_{23}\eta_{34}\eta_{45}\rho_0 c_0^2}{\omega\eta_2\eta_3\eta_4\eta_5 V p_0^2}$$
$$= L_{w,2} + 10\log(\frac{\eta_{23}\eta_{34}\eta_{45}}{\eta_2\eta_3\eta_4}) - 10\log(\frac{V}{T}) + 14 \tag{2}$$

The impact sound level on the flanking path is:

$$L_{p,flank} = 10\log(\frac{p^2}{p_0^2}) = 10\log\frac{W_2\eta_{23}\eta_{34}\eta_{46}\eta_{65}\rho_0 c_0^2}{\omega\eta_2\eta_3\eta_4\eta_6\eta_5 V p_0^2} \tag{3}$$
$$= L_{w,2} + 10\log(\frac{\eta_{23}\eta_{34}\eta_{46}\eta_{65}}{\eta_2\eta_3\eta_4\eta_6\eta_5}) - 10\log\left(\frac{V}{T}\right) + 14$$

Where ρ_0 is the density of the air, c_0 is the velocity of the air, p_0 is the reference sound pressure.

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The total impact sound level in room 5 is:

$$L_p = L_{p,direct} + 10\lg[1 + 10^{-\frac{L_{p,direct} - L_{p,flanking}}{10}}] \quad (4)$$

where V and T are the volume of room 5 and the reverberation time in room 5 respectively.

3. Material Parameters

The above theoretical model should be compared with the existing data to verify the reliabiliy of the theory. So, three kinds of floating floor with different interlayer are list in Table 1 and 2. And the physical parameters of the floor slab and face-layer are shown in Table 1. The resilient interlayer was closely connected with the floor, Mineral wool, Fibrous resilient and Polystyrene foam are selected as a resilient interlayer, whose physical properties are shown in the Table 2.

Table 1. Properties of the face-layer and reinforced concrete slab.

Name	Density ρ (kg/m^3)	Thickness d(m)	Young modulus E(N/m^2)
Timber floor	542	0.022	4.0x10^9
Reinforced concrete slab	2200	0.120	2.8x10^{10}

Table 2. Properties of the resilient layers.

Resilient Interlayer	Thickness (mm)	Stiffness coefficient （KN/m^2）	Damping
Mineral wool	15	86	0.12
Polystyrene foam	3	165	0.05
Fibrous resilient	35	77	0.17

As seen from Table 2, polystyrene foam has the highest stiffness and fibrous resilient has lowest stiffness which exhibit favorable resilient among three kinds of resilient interlayer. If these resilient materials are adopted as the interlayer, the coupling loss factor between the two slabs should be determined.

4. Results and Discussion

The measured and predicted data were compared as shown in figure 5-8. The floating floor contains a 140mm concrete floor, a resilient interlayer and a 10mm oak wood face layer. And these measurement are conducted in according with Standard ISO140-8.

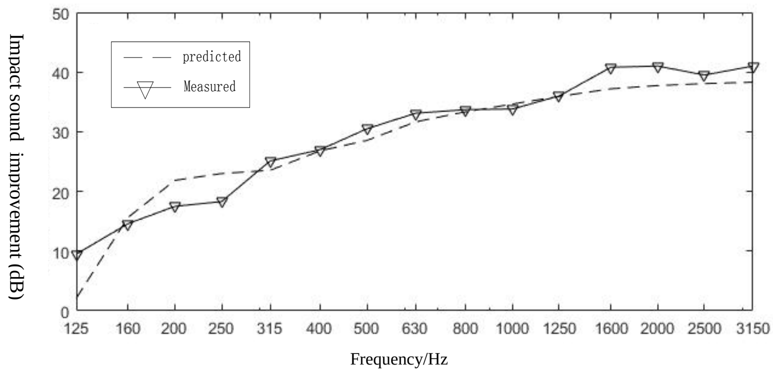

Figure 5. Measured and predicted impact sound level enhancement of a floating floor with 15 mm mineral wool interlayer (K=86KN/m^2)

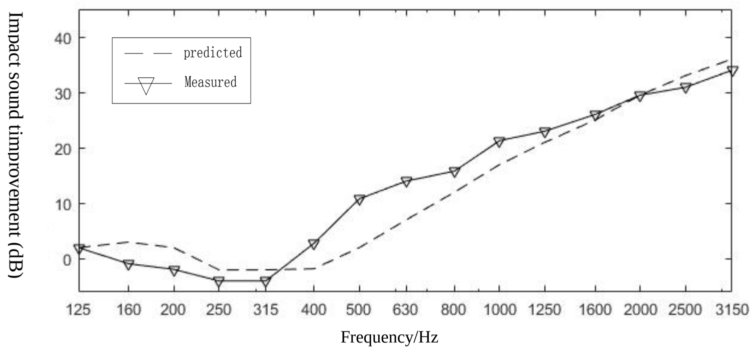

Figure 6. Measured and predicted impact sound level enhancement of a floating floor with 4mm Polystyrene foam interlayer (K=77KN/m^2)

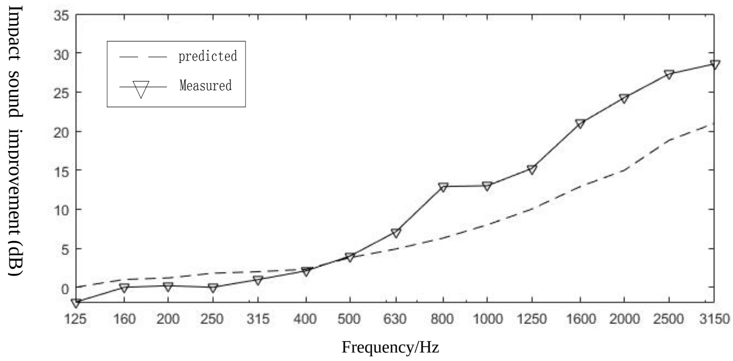

Figure 7. Measured and predicted impact sound level enhancement of a floating floor with 4mm Fibrous resilient interlayer (K=165KN/m^2)

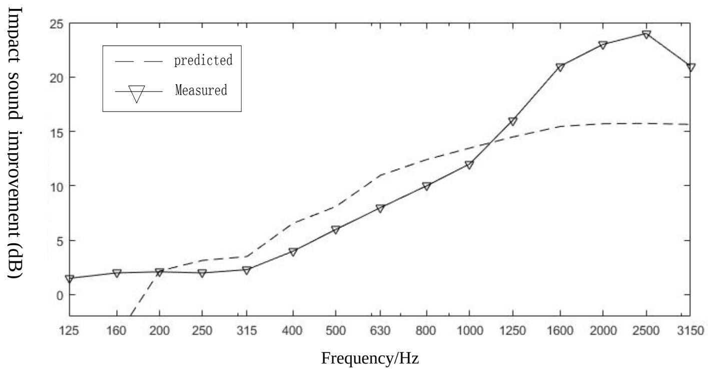

Figure 8. Measured and predicted impact sound level of a concrete floor with no interlayer

As shown in Fig5-8: the impact sound transmission is attenuated due to the effect of resilient interlayer within a floating floor, and it's insulation varied with properties of the interlayer material. Suitable interlayer material and it's thickness are chosen to obtain favorable performance of sound insulation. Polystyrene foam, fibrous resilient have higher impact sound insulation at middle and high frequency range, and not same at low frequencies. For instance, a 4mm polystyrene foam interlayer don't have high impact sound reduction below 315Hz, but it have obvious impact sound reduction at middle and high frequency range, especially above 1000 Hz, and it's average sound reduction index reaches above 28dB.

There are four flanking transmission paths through the building members, this paper selected one typical flanking path to analyze impact sound pressure level and compare it's values between direct path and flaking paths. And the floating floor composed of resilient interlayer material was adopted to calculate the impact sound pressure level: with fibrous resilient, polystyrene foam and without interlayer. These results are shown in figure 9-11.

By the comparison of three group of data, within the whole 1/3 octave frequency band range, the first group of floor structure, with wooden face-layer and without resilient interlayer, has higher impact sound insulation below 500Hz than that at other frequency range. Meanwhile, The dominant sound transmission is still the direct one, since the SPL on the direct path into the downstairs room is 10 dB more than those on any flanking path, and the two sound pressure level superposition, the total sound pressure is increased by only 0.1dB, therefore, there was no obvious influence of the flanking transmissions of the structure without resilient interlayer on overall sound pressure level in downstairs room.

After the comparison of the floating floor with three kinds of resilient materials of interlayer, It can be found that a floating floor with higher stiffness interlayer exhibits poor sound insulation on direct path. Conversely, favorable sound insulation can be obtained. But, the resilient materials with low stiffness barely meet the requirements of strength.

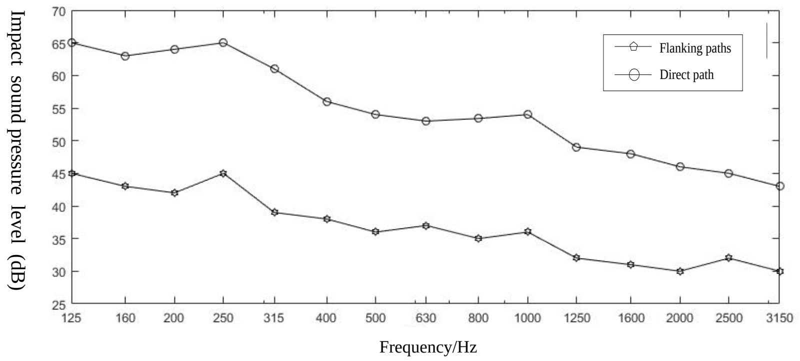

Figure 9. Impact sound level of two paths across a floating floor with 20 mm fibrous resilient interlayer(K=165KN/m^2)

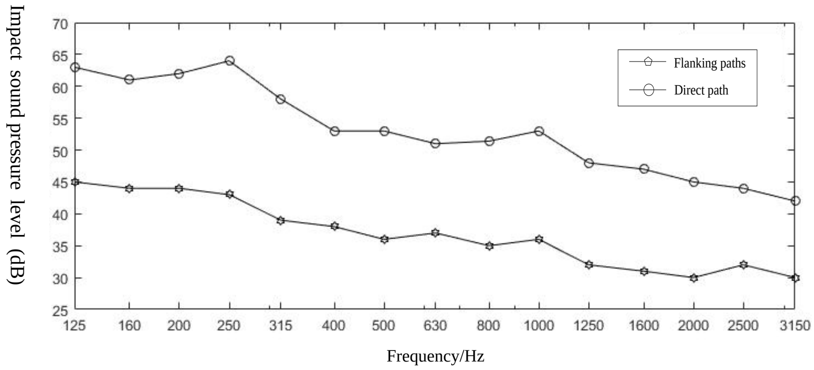

Figure 10. Impact sound level of two paths across a floating floor with 20 mm polystyrene foam interlayer(K=77KN/m^2)

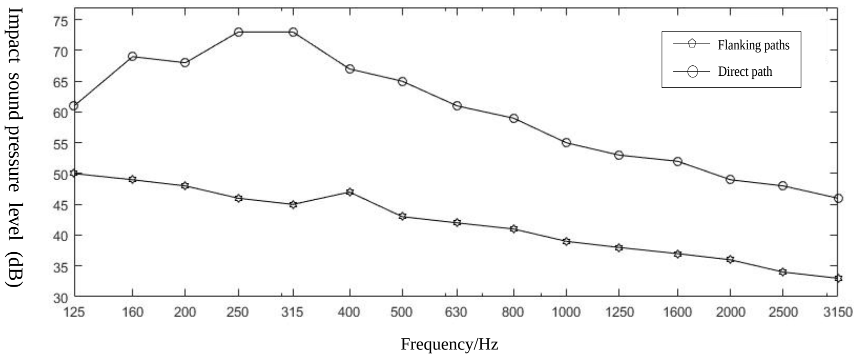

Figure 11. Impact sound level of two paths across a concrete floor without interlayer

5. Conclusions

The SEA model for impact sound transmission across a floating floor is established to determine two kinds of impact sound transmission ---direct path and flanking path, and equilibrium equations of a floating floors is gained by considering the performance of bending wave, which solves the problem of structural acoustic transmission through a resilient interlayer. And according to this SEA mode, the prediction method of the impact sound pressure level of floating floor structure is derived. The accuracy of the calculation can be verified by comparing with the measured data. The method is employed to predict the sound insulation of the floating floor accurately and provide a guidance for the sound insulation design.

The comparative analysis of the impact sound pressure level come from direct path and flanking paths to downstairs rooms is carried out, it is revealed that the sound insulation of floating floor is mainly affected by the direct path, the difference of impact sound pressure level between direct path and flanking paths is almost 20dB, when the resilient interlayer with different stiffness coefficients is used, and the stiffness coefficient decreased gradually.

6. Acknowledgement

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7. References

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