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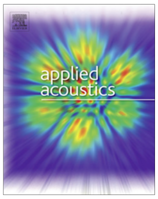

A quest for error factors in predicting heavy weight floor impact sound levels using measured data in existing residential buildings

Toshiyuki Okano *, Shinichirou Koyanagi

Takenaka Research and Development Institute, 1-5-1, Ohtsuka, Inzai, Chiba 270-1395, Japan

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ABSTRACT

A number of datasets regarding the heavy weighted floor impact sound level and the driving point impedance level, i.e., twenty times the common logarithm of driving point impedance at an exciting point, were measured in existing residential buildings before the floor finishing of the excitation room and the ceiling finishing of the receiving room were installed. These data were compared to the calculated values by the impedance method, i.e., a practical method that estimates vibration energy of an excited slab using the driving point impedance at the exciting point as a major factor, as well as those using the Finite Element Method (FEM) models of slabs. Furthermore, correlations between the residual errors and the major dimensions of the receiving rooms were investigated. Two major error factors were found to influence the calculated values by the impedance method. The spectral characteristic of the tire impact source within the 63 Hz band effectively decreased the prediction errors when it was included in the calculation and combined with the FEM models of slabs. The length of the shorter side of the receiving room plan correlated to the residual errors of the receiving rooms having a pair of flat parallel walls. These errors arise from the fact that the receiving points were placed at the central and quarter positions within the wall distance, where the nodes of the horizontal mode exist. It was not possible to identify another dimension of the receiving room that significantly correlates to the residual errors of the prediction.

1. Introduction

In Japanese residential buildings, the sounds caused by walking without wearing shoes or caused by children's running or jumping have been categorised as heavy weight floor impact sounds since the 1970s. The floor impact sound insulation for such a source has been measured using a tire impact source as a standard heavy impact source [1].

The "impedance method" is widely used as a practical method to predict the heavy weight floor impact sound level [2–4]. This method conveniently estimates vibration energy of an excited slab from the driving point impedance at the exciting point as a major factor. The 63 Hz band usually decides the rating of the insulation, and the prediction errors of the floor impact sound levels are sometimes as large as 5–10 dB. Because the errors are equal to or larger than the step size of the rating, i.e., 5 dB, they tend to decrease. As a more precise method, the numerical analysis method, for example, the FEM analysis method has been applied to the prediction problem [5]. However, in practice, such a precise method is not used so frequently because it is an intensive method. Further, the use of the FEM model is usually limited only to calculate the driving point impedance [6]. Such a method is just a partial replacement of the impedance method flow and is not fully effective in decreasing prediction errors.

On the other hand, the major factors that cause the errors have not been fully studied. The purpose of the present study is to extract some error factors empirically from a considerable amount of measured data in existing residential buildings. At first, the relationship between the driving point impedance level and the floor impact sound level is confirmed. The relationship is then compared with the corresponding relationship derived with FEM models to rate the radiation power of a slab and the floor impact sound level. A further study is conducted to extract other factors that are caused by the attributes of the receiving room.

Certain other error factors may arise from floor finishing materials, such as the double leaf floor panel and the suspended ceiling. However, the present study only examines the condition in which finishing materials are not installed, i.e., the slab is directly excited, and the sound is directly radiated to the receiving room.

2. Outline of the measurement in existing residential buildings

Measurements are carried out in 42 pairs of excitation and receiving rooms in 9 residential buildings under construction.

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* Corresponding author. Tel.: +81 476 77 1387.
E-mail address: Okano.toshiyuki@takenaka.co.jp (T. Okano).

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Table 1
Summary of the measured residential buildings.

Name	Area of slab (m^2)	Attributes of the building		Number of measured pair of rooms
		Type of slab	Type of partition wall between dwelling units	
A	80, 290	Composite slab using a pre-stressed concrete hollow core panel	Dry partition wall	6
B	290		Dry partition wall	4
C	65–85		RC structural wall or dry partition wall	5
D	105, 110	Homogeneous single plate slab	RC structural wall	5
E	55–105	Slab having ellipse columnar voids	RC structural wall	5
F	55–65	Homogeneous single plate slab	Dry partition wall	5
G	30–40	Composite slab using a pre-stressed concrete hollow core panel	Dry partition wall	5
H	55		Dry partition wall	2
I	45, 80		RC structural wall or dry partition wall	5

Table 1 shows a summary of the major attributes of the buildings. Slabs have the equivalent thickness as a homogeneous single plate, from 250 to 300 mm, and their area varies from 30 to 290 m^2, and most of the slabs belong to the category of so-called "large area slab". There are three types of slabs, a homogeneous single plate slab, a slab having ellipse columnar voids, and a composite slab with a pre-stressed concrete hollow core panel. Within the very large slab, which has an area of 290 m^2, four dwelling units are placed, connected to each other with a thick double leaf dry partition wall in between. Most of the other slabs cover one dwelling unit area each.

In each pair of rooms, the receiving room is placed just under the excitation room, connected to each other with a slab in between. The finishing materials of the floor in the excitation room and the suspended ceiling boards in the receiving room are not installed yet. The partition walls that limit the receiving room's sound field are installed.

The driving point impedance level, i.e., twenty times the common logarithm of driving point impedance at an exciting point, of the five excitation points, the floor impact sound level using the tire impact source at five receiving positions for every excitation point, and the reverberation time of the receiving room were measured in each pair. Fig. 1 shows the configuration of the receiving points. The central point and four quarter points on the diagonals of the plan were selected, as is usually the case in this type of measurement. The measured sound levels were averaged over five receiving positions in the dimensions of energy, and a value for each excitation point was determined. The heights of the receiving points were varied from 0.6 to 1.8 m above the floor with 0.3 m steps [7]. This variation is to avoid the influence of the vertical acoustical mode that usually falls into the 63 Hz band. Such a mode has a node at a height between 1.2 and 1.5 m. The excitation points are set at the same place in the plan as at the receiving points. The averaged absorption coefficient of each receiving room was determined from the measured reverberation times. Because the values did not vary much among the receiving rooms, they were averaged over all receiving rooms, and the absorption power of each receiving room was calculated by multiplying the averaged value and the total area of the room.

3. Relationship between the driving point impedance and the floor impact sound level

The relationship between the floor impact sound level and the powered average of the vibration velocity is shown as Eq. (3.1) [4]. Considering the transmission of the vibration within a slab, the floor impact sound level is related to the transmission impedance $Z_{T,ij}$, which shows the attenuation from the driving point to a receiving point, as:

$$L_{i,Fmax} = 10\log_{10}(|v|^2 4\rho_0 c_0 \kappa S_e / A) + 120 + \Delta C \tag{3.1}$$

$$L_{i,Fmax} = 10\log_{10}\left(1/S_e \sum_j (|F_E|^2 |Z_{T,ij}|^2) dS_j 4\rho_0 c_0 \kappa S_e / A\right) + 120 + \Delta C \tag{3.2}$$

where $L_{i,Fmax}$ is the impact sound pressure level (dB), F_E is the root mean squared value of the excitation force by the impact source (N), $Z_{T,ij}$ is the transmission impedance from an excitation point i to a receiving point j (kg s^{-1}), $\rho_0 c_0$ is the acoustic impedance of the air (kg m^{-2} s^{-1}), S_e is the area of the radiation surface (m^2), κ is the radiation coefficient of the slab, A is the equivalent absorption area of the receiving room (m^2), and ΔC is the correction value for the dynamic property of the sound level meter. $Z_{T,ij}$ is modelled as shown Eq. (3.3) [4],

$$Z_{T,ij} = Z_\infty / (\chi_{C,i} \chi_R \chi_{T,ij} \chi_{C,j}) \tag{3.3}$$

where Z_∞ shows the impedance, which is defined by the sectional property of an infinite plate (basic impedance), χ_{Ci} shows the correction for the beam restriction at the excitation point, χ_R shows the correction for the resonance of the plate, $\chi_{T,ij}$ shows the attenuation through the transmission from the excitation point to the receiving point, and χ_{Cj} shows the correction for the beam restriction at the receiving point. Eq. (3.4) shows that the floor impact sound level is given by two variables, W_e and A, where W_e is the product of the power of the excitation force and the averaged reciprocal of the power of $Z_{T,ij}$ over the radiation surface. When the excitation is limited to cases using a standard impact source in a specific frequency band, terms that are not dependent on the excitation point and the attributes of the receiving room are assumed to be constants.

$$L_{i,Fmax} = 10\log_{10} W_e + 10\log_{10}(4\rho_0 c_0 \kappa) - 10\log_{10} A + 120 + \Delta C \tag{3.4}$$

$$W_e = \sum_j |v_{ij}|^2 dS_j = |F_E|^2 \sum_j (1/|Z_{T,ij}|^2) dS_j \tag{3.5}$$

In cases where the excitation point and the receiving point are identical, the attenuation through transmission within a slab is negligible. Eq. (3.3) takes on the form of Eq. (3.6), Z_i being the driving point impedance.

$$Z_i = Z_\infty / (\chi^2_{C,i} \chi_R) \tag{3.6}$$

Substituting Eq. (3.3 into 3.5) yields Eq. (3.7). Eq. (3.4) can then be written as Eq. (3.8).

$$W_e = \sum_j |v_{ij}|^2 dS_j = |F_E|^2 / |Z_\infty|^2 \chi^2_{C,i} \chi^2_R \sum_j (\chi^2_{T,ij} \chi^2_{C,j}) dS_j \tag{3.7}$$

$$\begin{aligned} L_{i,F\,max} = {} & 10\log_{10}|F_E|^2 + 20\log_{10}(\chi_{C,i\chi_R} / |Z_\infty|) \\ & + 10\log_{10} \sum_j (\chi^2_{T,ij} \chi^2_{C,j}) dS_j + 10\log_{10} 4\rho_0 c_0 \kappa \\ & - 10\log_{10} A + 120 + \Delta C \end{aligned} \tag{3.8}$$