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A MODIFIED CALCULATION METHOD AND ITS ACCURACY FOR FLOOR IMPACT SOUNDS ON LARGE-SPAN SLABS FROM SOFT AND HEAVY IMPACT SOURCES

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ABSTRACT

The impedance method is a commonly used method in Japan to predict floor sounds by soft and heavy impacts. However, the impedance method overestimates sounds from large-span slabs such as those for condominiums, which have approximately 80 square meters. Because this standard method originated from investigations of slabs with an area of around 25 square meters, it should not be applied to large-span slabs. We modified the standard method so it applies to these large-span slabs. Calculations using our method agreed within 1 dB on average of measurements with a standard deviation of 3 dB.

1 - INTRODUCTION

Structural design technology is developing that allows larger-spanned building structures. Consequently, in Japan, more condominiums are being constructed with large-span slabs of approximately 80 square meters: nearly equal to the area of an average one-family condominium. This structural method allows architectural designs without the restrictions of beams and columns. On the other hand, the demand for better sound insulation in buildings is increasing. Because insulation from impact sounds is one of the most important aspects that affect the sound insulation of floors, Kimura and Inoue [1] developed the impedance method to calculate floor sounds caused by soft and heavy impacts. This calculation method is widely used in Japan and simple enough to use with spreadsheet software. However, because this method was developed using slabs of about 25 square meters, the impedance method overestimates these sounds on large-span slabs. Therefore, we modified the method for use on large-span slabs.

2 - THE STANDARD IMPEDANCE METHOD

The impedance method is commonly used for assessment of heavy weight floor impact sound in Japan. This method is very simple and useful for multi-family dwellings by ordinal construction method. The equation of the prediction method is,

$$L_j = 10\log_{10}\left[\frac{F_{rms}}{Z_{b,T}} \cdot \rho_0 c_0 \cdot k \cdot \frac{4S_{eff}}{A}\right] + 120 + \Delta C \qquad (1)$$

where L_j is the floor impact sound level per octave band (dB), $\rho_0 c_0$ is the acoustic resistance of air (kg/(m^{2}s)), ΔC is the dynamic characteristics correction value of the sound level meter (dB) as from Table 1, F_{rms} is the effective value of the impulsive force by the freefalling-tyre impact source (N) from Table 1, k is the acoustic radiation coefficient, S_{eff} is the effective sound radiation area (m^2), A is the absorption area of sound receiving room (m^2), and $Z_{b,T}$ is the modeled impedance level as mentioned section 4.

The effective sound radiation area is calculated from the area of the interested room minus the peripheral area within the quarter of the wavelength of bending wave for each octave band center frequency from the fixing beams or girders of interested floor.

Octave-band center freq. (Hz)	63	125	250	500
Impulsive force level 20logF_{rms} (dB)	37	22	12	4
Correction Value ΔC (dB)	9.8	8.3	6.5	5.6

Table 1: Impulsive force F_{rm} and correction value ΔC.

3 - MEASUREMENT

Heavyweight impact sound measurements used a bang-machine (freefalling tyre) according to JIS A 1418 and were done in 190 rooms at more than 30 sites. Hence, for five measurement points, we measured the average peak sound pressure level from tyre blows for each octave band with a FAST time constant at a sound receiving room L_j for five impact points. The average of L_j (for the five impact points) is the impact sound pressure level L.

The results for different slab thicknesses are shown in Fig. 1. Although there is significant scatter, the results show a decrease with increasing slab thickness.

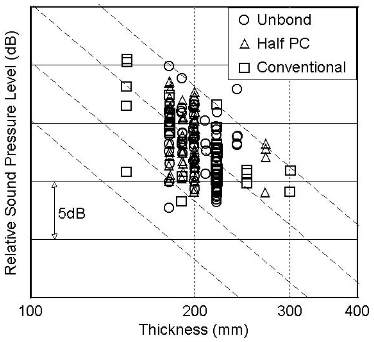


Figure 1: Floor impact sound vs slab thickness; the dashed line shows the decay from increment of impedance level of an infinite slab.

Figure 2 shows the relationship between slab area and measured impact sound. The correlation between slab area and impact sound insulation is small, but there is a weak decreasing sound pressure level trend with increasing slab area.

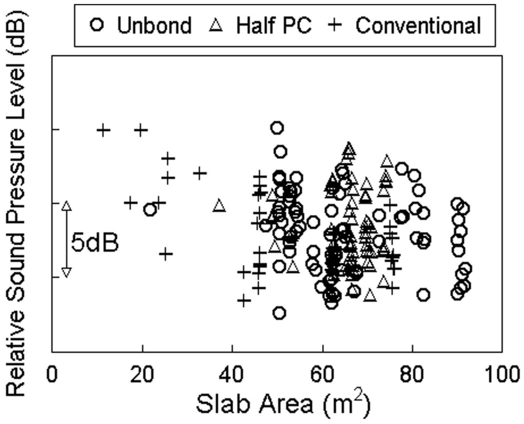


Figure 2: Floor impact sound vs slab area; all results L are normalized to a slab thickness h of 200 mm using $L' = L - 40\log(h/200)$.

Figure 3 shows the relationship between the floor impact sound pressure level (FAST peak) and the point impedances calculated from the vibration-acceleration responses using an impact hammer. This result shows that the impact sound can be calculated from the characteristics of slab vibration as reported by Gerretsen [2].

4 - CALCULATION MODEL OF DRIVING POINT IMPEDANCE

According to the impedance method, the impedance of each excitation point $Z_{b,T}$ is shifted from that of an infinite length slab of the same section depending on the slab peripheral boundary condition and the natural frequency. That is,

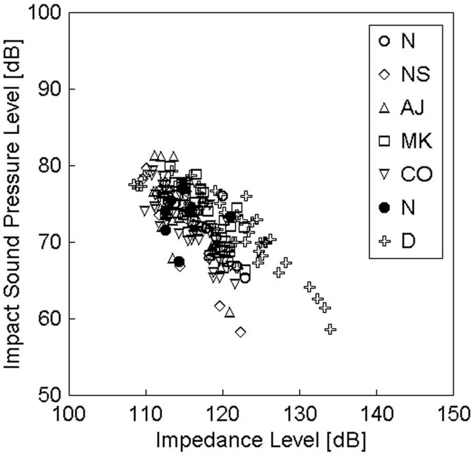


Figure 3: Measured driving point impedance level vs measured impact sound pressure level for each impact point at 63 Hz octave band.

$$Z_{b,T} = Z_{\infty} + \Delta L_f + \Delta L_Z \tag{2}$$

where $Z_{\infty} = 8\sqrt{B/m}$. B is the flexural rigidity of the floor slab, m is the surface density of the floor slab.

The second term of eqn. (2) ΔL_Z is the increment of impedance level by the constraint of the slab at the boundary. The edge fixing level was given using the ratio of the distance from the slab edge x and the wavelength λ_b of the bending wave. Although λ_b at impact frequency is used in the standard impedance method, we propose using λ_b at each octave band center frequency [3].

The reasons are as follows: 1) Dispersions of measured impact sounds caused by the difference of measurement point are larger at lower frequency (Fig. 4), although these dispersions are partly caused by the sound field characteristics in the receiving room. 2) Using the octave-band-center frequency fits the data better as shown in Fig. 5. The reported [4] frequency-independent average vibration acceleration exposure level from edge fixing contrasts with our result and thus might mean that this phenomenon is nonlinear.

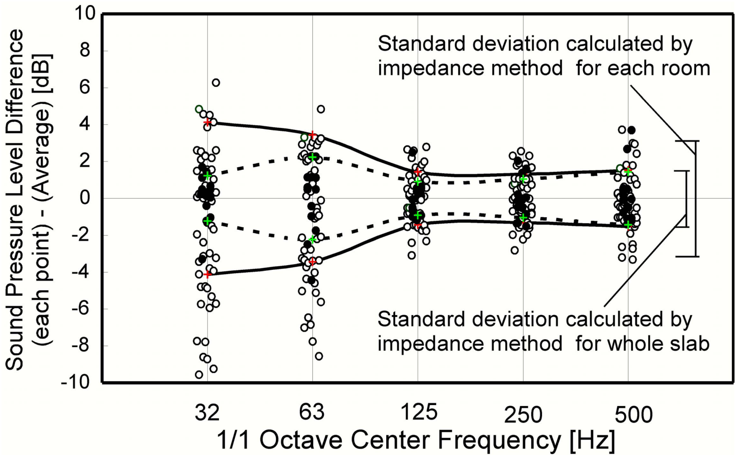
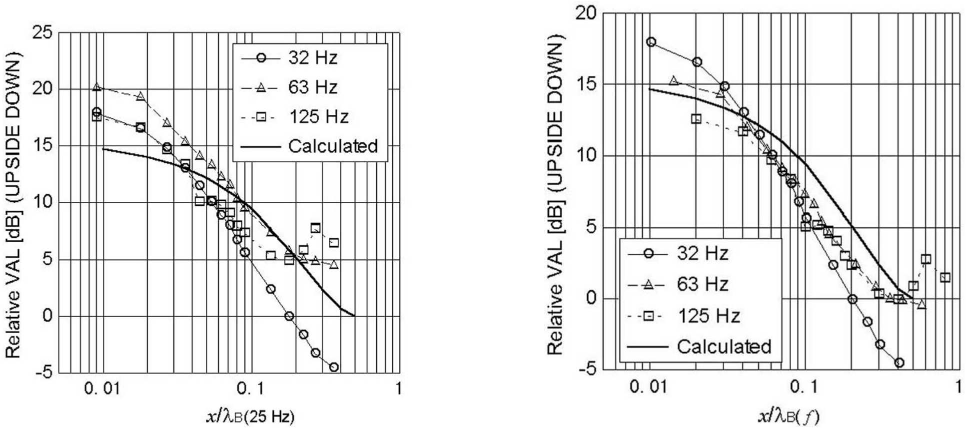


Figure 4: Example of dispersions of measured impact sound levels (before the walls in family-unit installed, circle: sound pressure level for each room; dot: sound pressure level for family-unit (whole slab); thick line: standard deviation for each room; broken line: standard deviation for whole slab).

The third variable in eqn. (2) ΔL_f, is due to the resonance of the slab with the natural frequency. Although Kimura [1] derived its decay as 3 dB/octave from measured damping factor, we modified it to vary according to eigen frequency of the slab as shown in Fig. 6 using the measured impedance characteristics of large-span slabs.



(a): Normalized by impact freq. (25 Hz).

(b): Normalized by each central freq.

Figure 5: Increment of average vibration acceleration level (peak value with FAST time constant) for each octave band versus two normalized distances between impact (tyre blow) point and girder of floor slab; the diagonal axis of (a) is normalized by wavelength of the bending wave of impact frequency of the tyre (25 Hz); (b) is by wavelength of each center frequency; the thick line is the regression curve of the increment of impedance level [1].

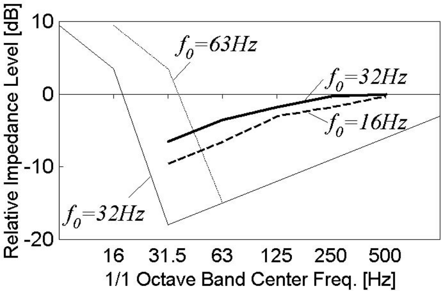


Figure 6: Model of impedance decrement by resonance (thin line: the standard impedance method; thick line: modified; f_0 denotes the calculated eigen frequency).

5 - FLOOR IMPACT SOUND CALCULATION

For large-span slabs, we propose using

$$L_j = 10\log_{10}\left[\frac{F_{rms}}{Z_{b,T}}\cdot \rho_0 c_0 \cdot k\right] + 120 + \Delta C \tag{3}$$

where $Z_{b,T}$ is the impedance level model as in section 4. The sound absorption and radiation area terms are eliminated in eqn. (3). Because, according to the measurement results, the effect of absorption is less effective for the FAST peak level of the impact sound and the direct sound of the impact was decisive. The differences between measured and calculated values are shown in Fig. 7. Calculations using our modified method (eqn. 3) agree with in situ measurements within 1 dB on average with a standard deviation of 3 dB.

6 - CONCLUSION

We modified the standard impedance method for large-span slabs and evaluated it against measurements. Although floor impact sounds might contain nonlinearities, we conclude that this modified method is sufficiently accurate to predict floor impact sounds in multi-family dwellings with large-span slabs.

REFERENCES

1. **S. Kimura and K. Inoue**, Practical Calculation of Floor Impact Sound by Impedance Method, *Applied Acoustics*, Vol. 26, pp. 263-292, 1989

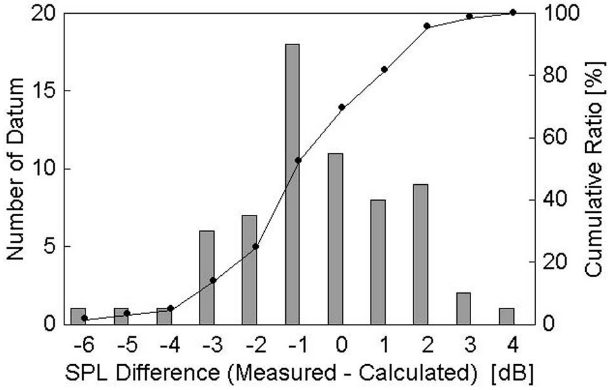


Figure 7: Differences between measured and calculated impact sound pressure levels at 63 Hz octave band.

2. **E. Gerretsen**, Calculation of Airborne and Impact Sound Insulation Between Dwellings, *Applied Acoustics*, Vol. 19, pp. 245-264, 1986

3. **T. Koga and M. Tano**, Prediction of Heavy Weight Impact Sound of Large Spanned Slabs, In *Proceedings of ASJ and ASA Joint Meeting, Honolulu*, pp. 73-76, 1996

4. **T. Yamauchi, S. Kimura, K. Inoue, S. Nakazawa and S. Nakamori**, Experimental Study on Vibration Characteristics of Large Span Slabs for Floor Impact (in Japanese), In *Proceedings of Annual Meeting Architectural Institute of Japan*, pp. 171-172, 1999