Evaluation of Floating Floor System with Steady State Dynamics Simulation in the Context of Impact Sound Level

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Abstract. Evaluation of floating floor at the design level imposes to take into account assumption of proper execution of this system, which means assertion of proper localization of dilatation. Aim of this research is to analyse usefulness of Steady State Dynamics (SSD) simulation in the context of floating floor performance and execution errors such as global or local lack of circumferential dilatation. For this purpose, two-storey building with one room at each floor was simulated. Floating floor system was applied at structural ceiling between upper and lower floor. Excitation of system was done by application of pressure with given frequencies at central part of floor. Three types of systems were analysed: system without floating floor, system with properly executed floating floor and system with floating floor short-circuited to walls. Application of dynamic bridge was done gradually - at each wall - till whole floating floor was short-circuited. In the result of correlation between akin in-situ test compatible with standards, normative prediction of weighted impact sound reduction index and SSD simulations results was evaluated. Moreover, influence of dynamic short-circuit on floating floor system was analysed. Finally flanking vibration transition between upper and lower room with different systems was discussed. Principal conclusion of performed analysis is fact that SSD simulation results are sufficient to show vibration velocity spectrum nature of changes between systems with and without floating floor. What is more application of dynamic bridges at circumference of floating slab makes given system similar structural ceiling only system, which meets with akin in-situ test in matter of acoustic performance – similar nature of results of impact sound level with and without floating floor. Nevertheless, SSD simulation results are hardly agreeable with normative prediction and in-situ test of weighted impact sound reduction index.

1. Introduction

This article provides simulations of floating floor dynamically short-circuited with wall compared with properly executed floating floor system. Additionally, comparison between floating floor system and structural ceiling only is done. Finally, flanking transmission results are presented. Space of analysis consist of vibration velocity of wall in room below and floating floor subjected to impact.

Vibroacoustics of floating floor systems are important part of noise engineering control and has been studied in many publications, exemplary [1-5]. In the light of following standard [6] 100 Hz up to 3150 Hz third octave bands are analysed. Calculation of weighted impact sound reduction index ΔL_w is based on dynamic stiffness of the resilient layer and surface mass of floating floor. Important factor is to execute designed system complying with good practice standard. In simplified way, this means to provide proper dilatation between floating slab and both wall and floor. Execution errors in
floating floor systems, such as lack of circumferential dilatation of slab may influence direct transmission of impact sound and also flanking sound transmission.

2. Assumptions and calculation method
In this paper 3D model in Abaqus Standard under Steady State Dynamics (SSD) simulation is analysed. Following assumptions are made:

2.1. Geometry
Given geometry shown in figure 1 and figure 2 represents 12 m² of floor as given in standard. Room heights are based on typical room height in Polish buildings and also in standards. [7, 8]

![Figure 1. Cross section of floor system](image1)

![Figure 2. Axonometric view of modelled system](image2)

2.2. Material data
Values given in table 1 are set basing on [9] values, considering cement/concrete elements. Values for elasticized Styrofoam are based on manufacturers data.

| Element               | Young modulus E [MPa] | Density ρ [kg/m³] | Poisson ratio ν [-] | Structural damping [-] |
|-----------------------|-----------------------|-------------------|---------------------|------------------------|
| Reinforced concrete   | 25000                 | 2400              | 0.17                | 0.05                   |
| Floor slab            | 20000                 | 1800              | 0.17                | 0.05                   |
| Styrofoam (elasticized)| 1                    | 25                | 0.30                | 0.10                   |

2.3. Mesh and simulation parameters
Quadratic formulation was used to prevent occurring of hourglass effect [10]. Brick elements are applied to provide most stable results [10]. Given size of mesh seed is dictated by two factors. First one is element thickness limitation. Second one is to provide for a quarter of wavelength proper mesh size. For concrete wave velocity is around 3400 m/s [11-13], which gives required highest mesh size of 17 cm. Detailed parameters are shown in table 2.
Table 2. Mesh and simulation parameters assumed.

| Mesh element   | C3D20R - a 20-node quadratic brick, reduced integration. |
|----------------|----------------------------------------------------------|
| Standard simulation | Steady State Dynamics                                      |
| Floor slab     | 10                                                       |
| Styrofoam      | 6                                                        |
| Floor          | 10                                                       |
| Walls          | 10                                                       |

2.4. Static scheme and dynamic short-circuit idea

Execution error of dynamically short-circuiting floor with wall - removing circumferential dilatation gradually - is done by applying interaction (stiff connection) between floating floor and wall as shown in figure 3.

![Figure 3. 3D FEM model with boundary conditions and short-circuiting idea](image)

Application of encastre boundary conditions at upper and bottom was dictated by following factor. It is worth to consider mathematical complexity of FEM model. To make an acceptable simplification instead of modelling roof and ground slab they were replaced by proper boundary conditions. Similar case can be found in [1]. Excitation force was applied at centre of floor, at area of 0.25 m² with amplitude equal to 1 N/m².

Analysis is performed as SSD simulation with linear material behaviour, in frequency range from 50 Hz to 5000 Hz giving results in FFT spectrum. To calculate weighted impact sound reduction index $\Delta L_w$ only 100 Hz up to 3150 Hz third octave bands are needed. Expansion of analysed spectrum is crucial for third octave filter application. Even though 100 Hz band is the lowest under consideration, to calculate it properly, lower frequencies are taken into account. To provide safe excess of frequencies wider spectrum is simulated. Similar case affects upper frequency limit of analysis.

2.5. Calculation method

After obtaining from simulation FFT spectrum of normal to surface velocity vibration of each panel it was recalculated using 1/3 octave filters to 100 Hz up to 3150 Hz bands.
2.5.1. **Filter formula from FFT to partial octave bands.** Formulas (1) and (2) were used to calculate 1/3 octave bands obtained from FFT spectrum. Formula (1) give values of filter function \( g \) in each frequency \( f \) Hz, assuming mid-band frequency \( f_m \) Hz and bandwidth designator \( b \) equal 3 for 1/3 octave bands. For any given mid-band frequency \( f_m \) yields the total RMS level within that fractional octave band \( L_{fm} \). For this equation \( p \) is power spectral density consisting of FFT \( S \) value of FFT bin, \( \Delta f \) FFT bin size [Hz] and \( u \) is noise power bandwidth equal to 1.

\[
g = \frac{1}{\sqrt{1 + \left(\frac{f - f_m}{f_m} \cdot 1.507b\right)^2}} \quad (1)
\]

\[
L_{fm} = \sqrt{\sum_{i=1}^{n} p_i \cdot g_i^2}, \text{where } p_i = \frac{FFT_i^2}{\Delta f \cdot u} \quad (2)
\]

2.5.2. **Power of vibrating panel.** Power of acoustic radiation \( W \) of vibrating panel can be obtained basing on formulas (3) and (4) where \( \langle \vec{v}^2 \rangle \) is the time- and space- averaged square of velocity of vibrations of analysed partition, \( \rho_0 \) is the air density [kg/m\(^3\)], \( c_0 \) is the sound velocity propagating in air [m/s] and \( S \) is the vibrating surface area [m\(^2\)] with \( \sigma \) being radiation efficiency factor [-]. Additionally, coincidence frequency \( f_c \) formula (4) where \( c_L \) is the velocity of longitudinal wave in panel (m/s), \( h \) is panel thickness [m], and \( c_0 \) is the velocity of sound in air [m/s], [14]

\[
W = \langle \vec{v}^2 \rangle \rho_0 c_0 S \sigma \quad (3)
\]

\[
\sigma = \frac{1}{\sqrt{1 - \frac{f_c}{f}}}, \text{where } f_c = \frac{c_L^2}{1.8 c_L h} \quad (4)
\]

2.5.3. **Sound level created by vibrating partition and impact sound level.** Basing on formulas (5) and (6) it can be assumed that impact sound level \( L'_{n} \) is roughly equal to power level of all vibrating panels in room, which is sufficient approximation for result analysis. In following formulas, \( A \) is value of the acoustic absorption in the room [m\(^2\)], \( A_0 = 10 \) m\(^2\), \( W_0 \) power reference level [W] and \( L_{rec} \) sound level in room [14, 15].

\[
L_{rec} = 10 \log \frac{W}{W_0} - 10 \log \frac{A}{4} \quad (5)
\]

\[
L'_{n} = L_{rec} + 10 \log \frac{A}{A_0} \quad (6)
\]

3. **Results and discussion**

Two exemplary results of velocity spectrum of surfaces resulted from simulations are presented below in figure 4. Presented results are only limited to two elements, because of its high amount and high density of values.
3.1. Impact level and power level difference.

Based on results of vibration velocity simulation, power level at each 1/3 octave band between 100 Hz and 3150 Hz for each panel at the model was calculated. Below in figure 5 there are presented results of 1/3 octave bands power levels with reference level of $W_0 = 10^{-15.2}$ W. Usually $W_0$ is equal to $10^{-12}$ W but assuming results should be positive, and from [6] it can be calculated that $L_{n,w}$ for concrete slab with thickness of 20 cm is equal to 70 dB, such change will result in translation of each value in the same manner.
Power level spectrum of vibrating structural ceiling shows clearly better (quieter) performance of floating floor system comparing to structural ceiling only and short-circuited system. Similar behaviour can be observed in in-situ tests. Calculating weighted impact sound level gives difference between systems $\Delta L_w = 16$ dB. According to [6] weighted impact sound reduction of this system with dynamic stiffness of resilient layer equal to 25 MN/m$^3$ and surface mass of 108 kg/m$^2$ should be equal $\Delta L_w = 27$ dB.

![Figure 6. Results of difference calculated between floating floor system and structural ceiling only](image)

Results presented in figure 6 shows difference between gradually dynamically short-circuited floating floor system and one properly executed. Additionally, to validate simulation results described difference of system with and without floating floor were compared with those similar from [16], where combination of Styrofoam and rubber mats with similar dynamic stiffness in sense of [16] was measured in laboratory. Power level difference was evaluated instead of impact level difference to compensate fact of lack of flanking in discussed in [16] due to dilatations of structural ceiling and wall set in laboratory. Another fact is that structural ceiling thickness, in article [16] is 14 cm and in model is 20 cm. In sense of [6] if impact level difference of system is calculated thickness of structural ceiling is neglected.

Impact level difference shows correlation between simulation and laboratory tests. Exceptions are low and high 1/3 octave bands of analysed frequencies. Greatest problem is in 100-160 Hz bands showing worsening of performance of floating floor.

3.2. Flanking transmission.  
Flanking transmission was calculated from the model. To validate those results comparison with [6] was chosen as shown in figure 7.
Dynamic short-circuit influence is visible in both cases. First case is that it has a high influence on power level of structural ceiling combining lowering performance of low frequencies – as in floating floor – with high power level of medium and high frequencies – as in structural ceiling only. Second case pertains to changes in flanking transmission. As it stated below, values of simulated flanking transmission are not compatible with [6] standard values. Although it can be seen increase of flanking transmission in short-circuited systems. Below in table 3 are results of averaged in spectrum flanking levels.

Table 3. Results of energy-averaged in spectrum flanking levels [dB].

| No floating floor | With floating floor | Floating floor short-circuit at direction x+ | Floating floor short-circuit at direction x+,x- | Floating floor short-circuit at direction x+,x-,z+ | Floating floor short-circuit at each direction | EN 12354-2 flanking |
|------------------|---------------------|---------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------------------|
| 13.00            |                     | 13.00                                       | 6.21 w/out 1 and 2 kHz bands                 |                                               |                                               | 1.12                |
| 3.13             | 6.21                | 5.24                                        | 4.66                                         | 5.47                                          | 7.57                                          |                     |

Two parameters are crucial considering flanking transmission [6]. First of them is stiffness of node connecting vibrating slab with wall. In these modes, total continuity of slab and wall was assumed. Due to this fact, there might be an increase of flanking transmission in structure. Second factor is mass of wall (flanking element). High mass of flanking element tend to lower flanking transmission. Although in model, flanking transmission is much higher than predicted by [6] it can be at least in nature of phenomenon, not in values, explained. Increase of sound insulation in general of main element, lowers its role in total sound level. Flanking element role remains more or less constant. Thus in result sound level originating from flanking will increase.

3.3. Spectrum characteristic points in properly executed and short-circuited system.
In simulation and in akin in-situ test performed by authors few common results can be observed. Floating floor system tends to increase level in low frequency bands. Short-circuited systems shows
changes in lower frequency as for floating floor, but in higher frequencies behaves as structural ceiling only system. Concrete ceiling only give increase of levels in band around 3 dB per octave. It will change for different value if surface mass varies.

Figure 8. Simulated impact sound level

Figure 9. Measured impact sound level in similar systems

Similar in this situation means as follows: thicknesses of systems layers were in range of 30% of those modelled. Dimensions of considered rooms were in range of 40% difference in case of structural ceiling and 20% of height of receiving room (one below).

4. Conclusions

Basing on obtained results SSD simulation method can be applied only in limited frequency spectrum in order to evaluate differences between analysed systems.

Structure simulated tends to have rapid drops and peaks across the spectrum. This can be caused by assumption of constant damping in all frequencies. Probably good approximation of real structure damping could be Rayleigh damping formulation changing in frequencies, depending on mass and stiffness matrix of the model.

Following obtained results and conclusions, in order to find model which complies with reality not only in nature of phenomenon but better in case of values, Explicit simulation with detailed damping data will be taken into consideration.

Simulation gives results similar in case of characteristic points of spectrum. Short-circuited floating floor system tends to have similar low frequency issues as properly executed system. What is more structural ceiling only system shows rise in impact level with frequency increase.

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