DOI: 10.61782/fa.2023.0579

ON THE LOW FREQUENCY IMPACT NOISE OF MASSIVE FLOORS – A CASE STUDY

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ABSTRACT

The issue of impact noise level is frequently discussed topic in relation to the locally or resonantly reactive floors. In practice, one can face the situation when the standardized requirements on flooring system are fulfilled but neighbors are still disturbed by low frequency impact noise generated by walking. To understand the reasons, sometimes only microphone (sound pressure based) measurements may not be sufficient enough. The interaction of the excitation source and ceiling systems and several effective numerical approaches to predict the damping ability of the ceiling system against impact excitation has already been demonstrated in literature. A good knowledge of individual parts of the structure and properties of the excitation source is essential in each new flooring system design or development process.

As part of the national grant VEGA 1/0205/22 focusing on low-frequency impact noise the precise analysis of chosen massive floor and its reaction on the tapping machine and standardized rubber ball excitation was investigated. The conventional measurement technique based on sound pressure measurement as well as vibration measurement analysis were compared. The analysis was supported by numerical model.

Keywords: *Measurement, Impact noise, Numerical simulation, Vibrometry***.**

1. INTRODUCTION

In practice, we may encounter that despite the fact that the ceiling structure meets the requirements for the impact sound insulation, residents complain about the disturbing low-frequency impact noise spreading through the structure from a neighbor, corridor, an adjacent staircase etc. This is also why we commonly encounter research in this area. Nowadays, the common part of research is the focus on the subjective perception of impact noise radiation relation to the type of impact source in contrast to the standardized single number rating of constructions.

It has been proven that the use of several types of excitation source is suitable for understanding the behavior of the structure (for example a combination of a tapping machine and a rubber ball). A good knowledge of the individual parts of the structure as well as the characteristics and properties of the excitation source are essential in each new flooring system design or development process.

The work of Rabold et al. [1] briefly summarizes approaches to the mathematical definition of the physical nature of the reaction of a hammer hitting the floor gradually since 1971 [2]. The ability of impact noise source precise definition is a way to more accurate prediction of the structure's response [3]. Moreover, the interaction of the impact source and the floor was demonstrated which manifests itself especially in the case of light ceilings or reactive floors [4, 5]. Ongoing verification and development of effective prediction models with the focus on footfall noise is underway [6,7]. The work of Roozen et al.

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numerically and experimentally verifies approaches of characterizing the acoustic response of dropping standardized rubber ball [8]. Motivated by these works, the following study was carried out.

This investigation was performed as a part of the national grant VEGA 1/0205/22 focusing on low-frequency impact noise and the precise analysis of massive floors and their reaction on the tapping machine and standardized rubber ball excitation. The conventional measurement technique based on microphone measurement as well as vibration measurement analysis were compared. The analysis was supported by numerical model.

2. METHODOLOGY

2.1 Floor structure

The heavy weight floor in the basement of Faculty of Civil Engineering (STU in Bratislava) was made available for this experiment. The dimensions of the ceiling were l_x=5.86 m and l_y= 2.68 m. The height of the receiving room was l_z= 2.73 m. The tested floor can be defined as clamped reinforced concrete ceiling 220 mm thick with a 50 mm cement screed (data from technical documentation from 1965). Already the first measurements showed that the resilient layer (unspecified in available technical documentation) was present between screed and ceiling. Sometimes we encounter such a situation during the reconstruction of older buildings. Therefore it was a challenge to determine the mass-spring-mass resonance frequency and derive the stiffness of the resilient layer from it to be able create numerical model of the analyzed floor.

2.2 Measurements

Several measurements were performed on the given structure. Measurements can be divided into three categories:

- the objective acoustic assessment of the ceiling structure according to the standards ISO 16283-2 [9] and ISO 717-2 [10] respectively;
- the structural response in order to obtain the calibration data for the numerical model;
- the determination of the excitation of a standardized tapping machine and a rubber ball.

The **objective acoustic assessment** procedure itself consisted of measuring the spatially averaged reverberation time of receiving room and the sound pressure level during the tapping machine excitation or of the maximum sound pressure level during the standardized rubber ball excitation. Six source positions were used for both cases. A rubber ball fell from a height of 1m onto the floor surface.

The **structural response** of the ceiling was determined in two steps:

1) Modal analysis of the screed was performed. The measurement grid consisted of 15x15 measurement points. The goal was to recognize the screed modal response and indicate mass-spring-mass resonance of floor.
2) In the second step the transfer function of the modal hammer impact excitation between the point on the top of the screed to the six accelerometers mounted on the bottom of the ceiling in the receiving room was measured (Fig. 1).

In both cases the calibrated modally tuned impact hammer PCB model 086C03 and the number of MMF accelerometers Type KS78C.100 were used. The NI cDAQ-9185 chassis including the NI9234 modules DAQ were used for data storing via LabView interface. All the data were processed in MATLAB programing environment.

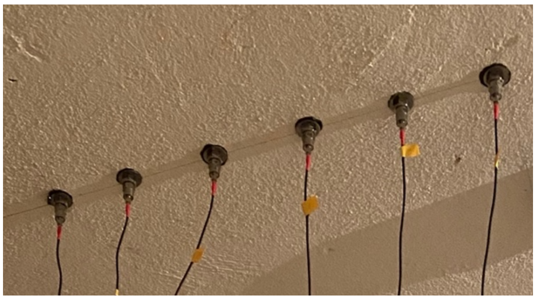

Figure 1. Vibration response of the ceiling measurement. Photo of accelerometers set mounted on the ceiling.

The **impact force excitation of tapping machine and rubber ball** was derived from their transfer functions (TFs). TFs were measured between excitation points of each hammer position (line of five excitation points in step of 10cm) and group of accelerometers (in equidistance 20cm from excitation points). During the TFs measurement the modally tuned impact hammer was used for floor excitation. After obtaining a set of TFs H_{xy}, the measurements were repeated with the Bruel & Kjaer tapping machine Type 3204 excitation. The wooden cover of the tapping machine was dismounted for this test. For the tapping machine in total 24 receiving positions were used (Fig. 2). The average excitation force was derived from

partial transfer functions of each hammer (based on 5x24 transfer functions in total).
The similar approach was applied also for rubber ball.

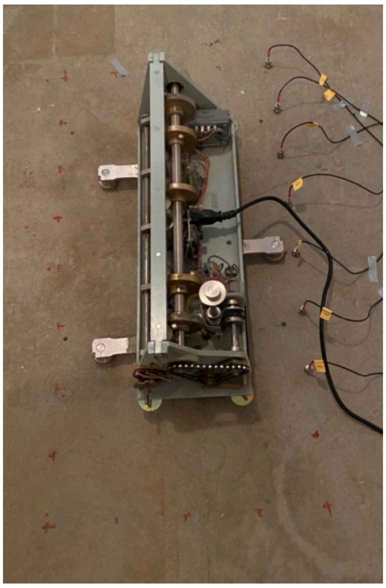

Figure 2. The tapping machine excitation force determination.

The excitation force F_{xy} separately for each tapping machine hammer was derived based on Eqn. (1):

$$\boxed{F_{xy} = \frac{A'_{xy}}{H_{xy}}} \tag{1}$$

Where A'_{xy} is the acceleration at point y emitted by tapping machine hammer at point x and H_{xy} is the transfer function between point x and y determined by means of modally tuned impact hammer excitation. The similar procedure was used for standardized rubber ball Svantek SP95 excitation. Only accelerometers were placed in line (distance from 20 to 120cm) (Fig. 3). The motivation to use the set of accelerometers mounted around the source was to prove that the floor system response is uniform around the excitation points and to have more reference data for numerical modeling.

Figure 3. View on the standardized rubber ball (Svantek SP95) and the set of accelerometers during the rubber ball force determination.

2.3 Numerical model

Based on the above-mentioned documents and measurements, a numerical model based on FEM was created. The tapping machine was modelled as a set of excitation points with defined phase shift. This is how the mutual time delay of the individual hammer hits was modelled. The frequency dependent excitation magnitude was derived from the measurements. Approximated stiffness of the so-called resilient layer was ca. 150MN·m^{-3}. The anechoic receiving environment was modelled by perfectly matched layer approach. Subsequently, the radiated sound power was derived from sound intensity on the receiving side. In the relation to the computer computation capacity the numerical simulation was performed up to the frequency 500Hz. The similar approach was used also for the standardized rubber ball.

3. RESULTS

For the purposes of this article, we only present a comparison of the spectra L_n and $L_{IFmaxVT}$ including the single number quantity (see figure 4).

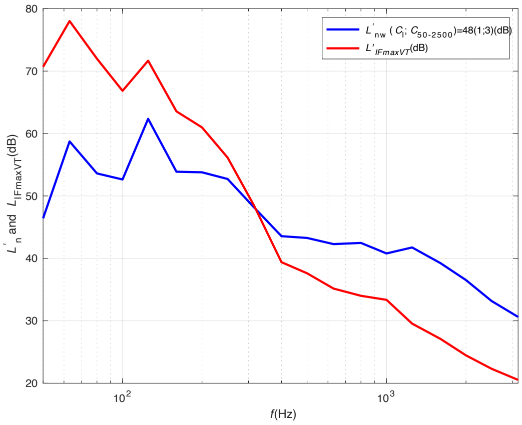

Figure 4. The spatially averaged impact noise level frequency spectra in 1/3rd octave band determined based on standardized tapping machine and rubber ball excitation.

The determined single number quantity was $L_{\mathrm{nw}}(C_{\mathrm{I}};\ C_{50\text{-}2500})$= 48(1;3) dB.
Relatively low value is caused by the resilient layer under the cement screed. The effect of resilient layer is especially evident in the spectrum above 500Hz (a reinforced concrete ceilings of these parameters without resilient layer should reach L_{nw} around 70 dB).
The simulation model was subsequently compared with the L_{n} and L_{IFmaxVT} spectrum for one excitation position of tapping macine / rubber ball (central point of screed in legend with index 1ex.p.) (see figure 5).

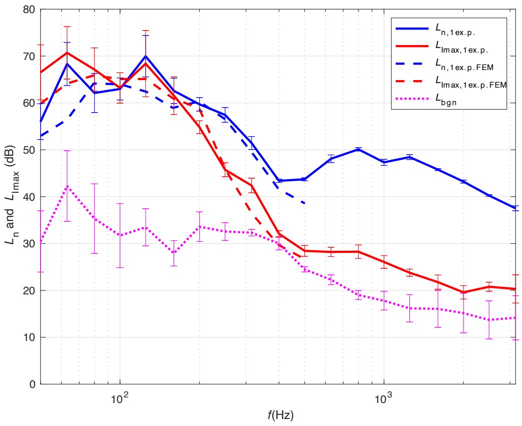

Figure 5. The spatially averaged impact noise level frequency spectra in 1/3rd octave band determined based on tapping standardized machine and rubber ball excitation – the comparison of measurements and simulations. Spectra are related to one excitation position.

Sound power level L_{P} spectra obtained by simulation were converted to sound pressure level L_{p} based on the theory described in [11]. Figure 5 also presents the standard deviation of the spatially averaged sound pressure level as well as the background noise level during measurements (BGN). Signal to noise ratio was in region of 400 to 500Hz central frequency lower than 4dB for rubber ball excitation case.
The results obtained by simulations and measurements correlate with each other within the measurement error range. The character of the impact source was demonstrated in the entire range of calculations. The rubber ball was more dominant especially in the spectrum below 200Hz (interpretable usually up to 650Hz). The measurement peak in region of 63Hz is related to the first room modes in l_y and l_z direction and in region 160Hz to the mass-spring-mass resonance of the floor system. Room resonances resonances are not obtained from numerical models because the receiving room was neglected. However, beside the mass-spring-mass resonance region also the effect of first structural mode of the screed was recognized in results (frequency region of 80Hz).

4. SUMMARY

In the presented case study we focused on the measurement and simulation of impact sound pressure level radiated from massive concrete ceiling with floating floor excited by a standardized tapping machine and rubber ball. As the properties of resilient layer were not known in parallel to ISO defined procedures of impact noise measurement the additional structural analysis was performed. The approximation of the impact sources generated force was performed too. The comparison of measurement and numerical simulations confirmed the acceptable agreement within the measurement error range.

5. ACKNOWLEDGMENTS

This work was supported by the Slovak national grant VEGA 1/0205/22. The authors also thank the company A&Z acoustics for lending part of the measuring equipment.

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