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# An engineering method to measure structure-borne sounds transmitted through the building partitions

# Metoda inżynierska pomiaru dźwięków materiałowych przenikających przez przegrody budowlane

**Abstract**

In this paper, the authors present an engineering method to identify the transmission paths of structure-borne sounds. The method is based on the use of a standardised impact sound source with an insulation case. The advantage of this approach is the possibility of obtaining repeatable results because the method allows the separation of structure-borne and airborne sounds; the latter do not interrupt the measurement even in the case of loose connections or elements of low acoustic insulation. The research on the verification of the method was performed on the façade of the Cracow Philharmonic building; the main structure-borne sound transmission paths were determined successfully. Knowledge of the sound transmission paths allows the subsequent design of efficient vibroacoustic protection.

**Keywords:** impact sound, vibrations, sound radiation

**Streszczenie**

W artykule zaproponowano inżynierską metodę identyfikacji dróg transmisji dźwięków przenoszonych drogą materiałową przy użyciu wzorcowego źródła dźwięków uderzeniowych z odpowiednią obudową dźwiękoizolacyjną. Zaletą tego podejścia jest możliwość uzyskania powtarzalnych wyników dzięki odizolowaniu dźwięków uderzeniowych od powietrznych, które nie zakłócają pomiaru w razie występowania nieszczelności lub elementów o niskiej izolacyjności akustycznej. W celu weryfikacji metody przeprowadzono badania budynku Filharmonii Krakowskiej – wyznaczono główne drogi transmisji dźwięków przenoszonych drogą materiałową. Ich znajomość jest niezbędna do projektowania skutecznej ochrony dźwiękoizolacyjnej.

**Słowa kluczowe:** dźwięk uderzeniowy, drgania, promieniowanie dźwięku

## 1. Introduction

In terms of building acoustics, sounds can be divided into two groups: sounds propagating in air (airborne sounds) and sounds propagating in solids such as the ground or the construction elements of buildings (structure-borne sounds). However, this distinction is not very rigorous since the airborne sounds may excite the construction of a building causing the formation of structure-borne sounds, and vice-versa – structure-borne sounds may induce airborne sounds in a gas medium (Fig. 1).

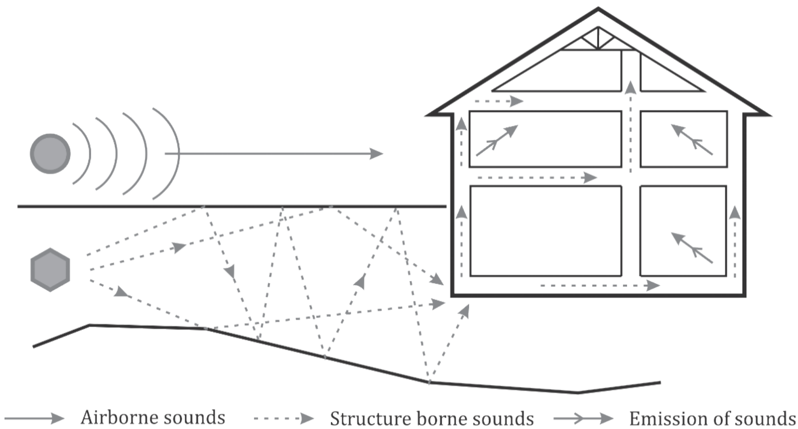


Fig. 1. Illustration of transmission paths for airborne and structure born sounds

Even though structure-borne and airborne sounds are strongly correlated, airborne sounds are much easier to be controlled and eliminated than structure-borne sounds because the transmission paths are usually clearly identified; the airborne sound transmission paths can be easily detected with standard measurement apparatus, specifically, sound pressure level meters. By contrast, the transmission paths of structure-borne sounds are very difficult to predict [4, 14]. Of course, there are a few methods which allow the determination of the structure-borne sound transmission paths; however, they have mostly been developed in the transportation industry – for example, experimental transfer path analysis (TPA) in the automotive industry [5, 13]. The TPA method is used for the analysis of the structure-borne sound transmission from point-coupled powertrains and wheel suspensions to vehicle bodies and for the analysis of transmission paths into vibration-isolated truck or tractor cabs, etc. The analysis of structure-borne sound transmission paths has also been developed in the railway industry [11, 12]; knowledge of structure-borne sound transmission paths enables effective noise protection in railway areas and prevents railway noise in the vicinity of newly designed railway routes.

In building acoustics, structure-borne sounds constitute a very important issue in all types of buildings; this is especially true in situations where the background noise level must be kept low, for example, in concert halls. Nevertheless, the determination of the structure-borne sound transmission paths is very difficult. The main problem which is encountered during this type of measurement is the simultaneous emission of airborne sounds during the excitation of the partitions with an impact sound source [7]. Building partitions very often include numerous elements of relatively low acoustic insulation, such as windows and doors. These elements allow the transmission of airborne sounds which, in turn, disturb the measurement of structure-borne sound transmission paths. Analysis of the current literature reveals that there are some methods for the analysis of structure-borne sound transmission paths in buildings such as that described in the ISO 140-4 standard [9]. However, this procedure is complicated and demanding since all the building elements, except for the one under study, must be covered with isolating materials. This is especially troublesome in the case of large halls. Moreover, this method does not allow the determination of more complex sound transmission paths and it is applied only to sources of airborne sounds. A different approach to the measurement of structure-borne sound transmission paths proposed by other authors is the use of a hammer as a sound source in examining multilayer concrete structures [1]. This method, however, does not allow the isolation of structure-borne sounds from airborne sounds. This is why, in the following paper, the authors propose their own method of measuring structure-borne sounds transmitted through building partitions. This solution allows the isolation and measurement of structure-borne sounds; as a consequence, it is possible to determine structure-borne sound transmission paths.

## 2. Measurement methodology

The proposed method for the identification of structure-borne sound transmission paths is based on the use of a standardised tapping machine as an impact sound source, housed within a thoroughly insulated case. In a standardised tapping machine, five hammers of a defined mass are used for the generation of the impact sounds. The distribution of the hammers and their parameters, together with the parameters of the whole construction of the tapping machine, are described in detail in the ISO 10140-5 standard [8]. The falling hammers of the tapping machine generate not only impact sounds but also cause the propagation of airborne sounds. In order to eliminate the influence of the airborne sounds on the final measurement results, the tapping machine must be covered with an insulation case of adequate parameters, i.e. the airborne sound insulation of such a case must be efficient enough. The construction of an insulation case was precisely described in, for example, [3]. The authors proposed a multi-layered construction in which the walls of the insulation case are built from layers of plaster board, mineral wool and plywood; the connections between the floor and the case are additionally sealed with putty. Such a solution ensures the airborne sound insulation of around 35–50 dB across the whole frequency range of interest, which is sufficient for such a measurement. The proposed insulation case is shown in Fig. 2. Because of the use of a standardised tapping machine, the generated sounds are stable and do not change over time; as a consequence, the results are not dependent upon the specific sound-source device used, as long as it meets the requirements given by the standard.

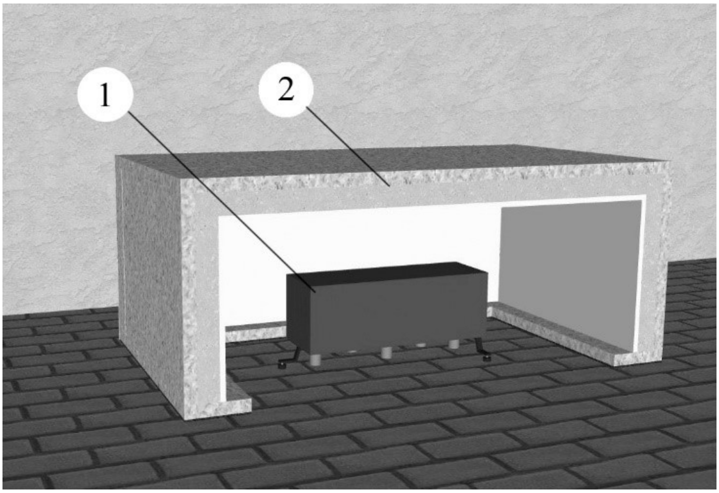


Fig. 2. A cross section through the insulation case (2) with a standardised tapping machine inside (1)

Having insulated the airborne sounds with the aforementioned insulation case, the vibrations of the ground can be measured in order to determine the intensity of the propagating structure-borne sounds. The comparison of the vibration acceleration levels on the surface of the construction elements under investigation, i.e. floors, walls and façades, enables the determination of the main propagation paths. The measurement of sound pressure level in turn enables the assessment of the impact sound levels. By correlating the spectra of the measured sound pressure levels and vibration signals, the most problematic frequencies can be determined; separate building elements can be investigated in terms of the frequencies within which the highest sound radiation can be observed.

## 3. The subject of investigation – Cracow Philharmonic building

In the following paper, the validity of the proposed engineering method to identify the transmission paths of structure-borne sound was examined. As an example site for the measurements, the Cracow Philharmonic building was chosen. In this concert hall, there has always been a major problem with structure-borne sounds mainly coming from two sources (Fig. 3). The first of these sources is the tram infrastructure (tram tracks run alongside two walls of the building – one of these is the external wall of the concert hall itself) and the second is the footsteps of pedestrians on the pavement along the external wall of the concert hall. It is crucial to determine which structure-borne sound transmission path is dominant; this knowledge is vital for the proper design of noise and vibration protection. In the following research, only one sound source was investigated – the footstep noise coming from the pavement on Zwierzyniecka Street, which is along the external wall of the concert hall. The tram noise was the topic of a separate analysis performed at AGH University of Science and Technology [10]. The main goal of the study presented in this paper is to

Fig. 3. View of the Cracow Philharmonic building together with the surrounding tram infrastructure and pavements [6]

determine the dominating sound transmission path. The proposed measurement method will also be verified in terms of its accuracy at identifying the precise transmission paths.

The standardised tapping machine, which imitates the real sound source (footsteps) was located along the external wall of the concert hall at a distance of 1.5 m from the wall and covered with the insulation case. The total area of the said wall is 327 m$^2$, including: brick wall – 270 m$^2$; window openings filled in with bricks – 47 m$^2$; wooden doors – 10 m$^2$. The total volume of the concert hall is 7045 m$^3$. The internal walls of the concert hall are made from brick, the floor is of a concrete construction and the ceiling is a suspended construction with plasterboard tiles. The measurements of the vibrations were performed on two sides of the external wall – inside and outside the building – at the same distance from the wall, and on the wall itself. The distribution of the measurement points is shown in Fig. 4 – four individual measurement points were inside the room and four individual measurement points were outside the room. The measurement points were distributed in a way which enabled obtaining

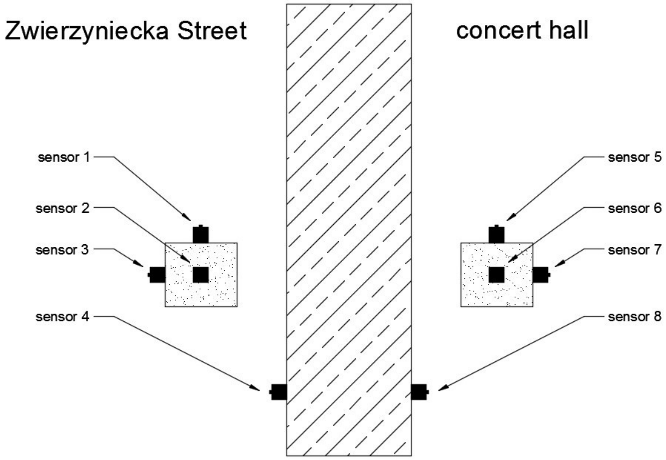


Fig. 4. Scheme of the placement of the vibration sensors [2]

information on the values and character of the vibrations of the floor on the three axes (the sensors were placed on the pavement and on the floor inside the concert hall) as well as on the wall in a perpendicular orientation. The sound pressure level of noise transmitted into the concert hall was measured at a distance of 1 m from the external wall.

The system used for the acceleration measurement consisted of a 3050-A-60 Brüel & Kjaer six-channel analyser together with six accelerometers (4500 A, Brüel & Kjaer) of the following parameters: sensitivity 1000 mV/g, measurement range 0.4 Hz – 6 kHz (± 10% amplitude), 2 Hz – 5 kHz (± 5° phase). The measurements were taken using a dedicated Pulse system. All the calculations and data analyses were performed in the MATLAB environment. For the measurement of sound pressure levels, a SVAN 912E sound level meter was used.

## 4. Analysis of the structure-borne sound transmission paths

As a result of the performed measurements, the authors obtained the spectra of the vibration acceleration recorded in all of the tested measurement points; the sound pressure level in the concert hall was also recorded. As the measurements indicate, the impact sound generated by the tapping machine propagates mainly in the vertical direction (the signal recorded by sensor 2 is characterised by the highest amplitude) although it also

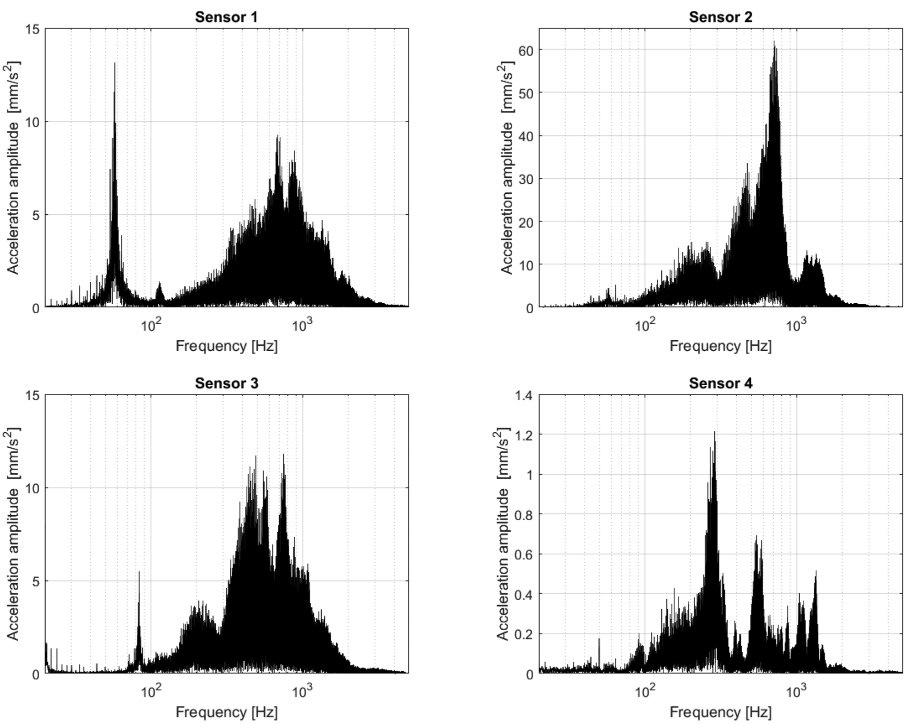


Fig. 5. The vibration spectra in the measurement points located outside the concert hall (each graph has a different scale on the y-axis)

propagates in the two horizontal directions (Fig. 5); however, the amplitudes of the signals recorded by sensors 1 and 3 are only around 21% and 19% of the maximum amplitude (as recorded in the vertical direction). Very little acoustic energy is transmitted through the wall – the amplitude of the signal recorded by sensor 4 is only 2% of what is recorded by sensor 2. The vibroacoustic background has no impact on the results – the amplitudes do not exceed 0.3 mm/s$^2$, which is negligible.

Analysing the acceleration spectra obtained in all the measurement points inside the concert hall (Fig. 6), it can be stated that the main structure-borne sound transmission path is through the floor, and the dominant direction of the vibrations is horizontal (sensors 5 and 7). In both cases, the prevailing frequency is about 360 Hz, which is also the dominant frequency in the spectrum of the noise measured inside the concert hall (Fig. 7). The amplitudes of vertical vibrations (sensor 6) and the vibrations of the wall on its inside (sensor 8) are not very significant – less than 30% of the maximum values recorded by sensors 5 and 7 – and they oscillate around the levels characteristic of background noise.

By means of the proposed engineering method to measure structure-borne sounds, it was possible to identify the main sound transmission path in the Cracow Philharmonic building from the impact source located on the pavement. As was indicated, this path is through

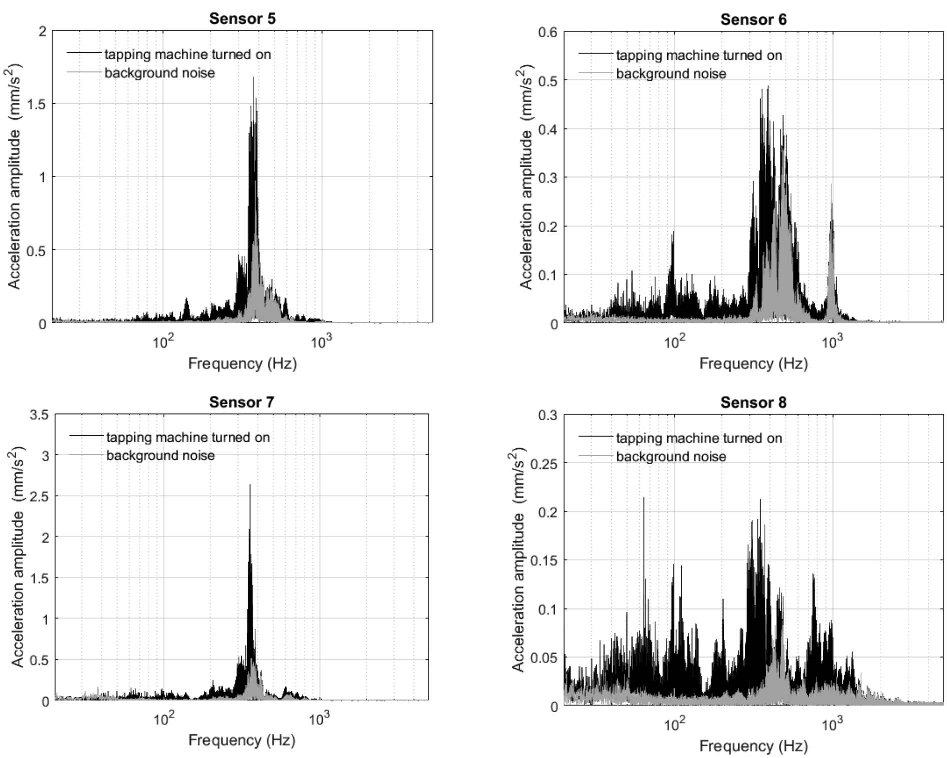


Fig. 6. The vibration spectra with background noise in the measurement points located inside (each graph has a different scale on the y-axis)

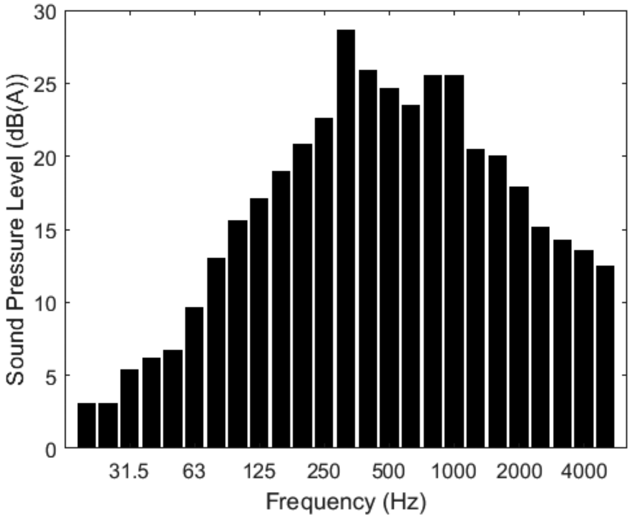

Fig. 7. Noise level inside the concert hall with tapping machine outside the concert hall turned on

the floor in the concert hall in the horizontal direction; the identification of the main sound transmission path enables the choice of proper vibroacoustic protection for the concert hall and as a consequence, will contribute to the reduction of the background noise inside the concert hall.

## 5. Summary and conclusions

In this paper, the authors' engineering method for the identification of the structure-borne sound transmission paths has been described and verified. The Cracow Philharmonics building was chosen as an example building to verify this method. The proposed method allowed the determination of the impact sound transmission paths from the external environment to the inside of the concert hall. In the research, the sound of footsteps from the adjacent pavement, imitated by a standardised tapping machine, was investigated. It was determined that the main structure-borne sound transmission path to the inside of the concert hall is through the concert hall floor in a horizontal direction. Knowing the main structure-borne sound transmission path will be crucial for the design of effective vibroacoustic protection.

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