Methods for determination of acoustic properties of building materials

Lukáš Fiala^{1,*}, Petr Konrád², and Robert Černý¹

¹Department of Materials Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic

²Experimental Centre, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Prague 6, Czech Republic

Abstract. Experimental determination of acoustic properties of building materials is an important task gaining higher importance due to demand for materials suitable for constructions located in places with high level of noise, typically in urban areas and places close to the areas with heavy traffic. In this paper, two types of experimental setups are arranged, and tested on steel prism and brick block. Transmitter-receiver method is based on exciting the tested material by one period of harmonic signal and analysis of response on two accelerometers placed on the excited and the opposite side of the sample. The second method is based on measurement of the sound pressure level in a system of two reverberation chambers by precise microphones and vibration analyzer. Transmitter-receiver measurement conducted on steel sample revealed the fact that further adjustment of the measurement setup and successive analysis is necessary. Measurement in reverberation chambers is convenient for comparison of acoustic insulation ability of heterogeneous building materials.

1 Introduction

Environmental deterioration caused by high level of noise is currently becoming a serious problem. It is particularly obvious in places with heavy traffic load and in or nearby industrial areas. Long-term exposure of noise affects not only human well-being and health which was proved by various studies [1-4], but also the condition of historical buildings [5]. Due to a high significance of such topic, noise pollution has been already monitored on various places all around the world [6, 7].

It is evident that satisfactory protection of people against adverse influence of the noise present in affected areas is crucially dependent on building materials and construction elements with good acoustic performance. Many studies already dealt with such topic, e.g. [8, 9].

In the Czech Republic, bricks and brick blocks are widely used in construction industry. Therefore, it is obvious an effort to improve acoustic properties of such type of materials e.g. by design of sealing plugs [10] and their application on brick blocks with incorporated

* Corresponding author: fialal@fsv.cvut.cz

voids that are subsequently filled up by convenient bulk materials attenuating sound propagation.

The very first step of assessment of acoustic performance of construction elements lies in experimental determination of acoustic properties of involved materials. In this paper, two types of acoustic measurements are presented together with experimental results from the conducted measurements.

2 Experimental part

The first experiment was based on determination of response on accelerometers during propagation of the defined acoustic signal through the steel sample. The similar experiments based on piezoelectric transducers were conducted in ultrasonic frequency band for detection of failures in materials [11]. The dimensions of the sample were of $(65.2 \times 49.8 \times 225.8) \text{ mm}^3$ and the mass 5618.7 g. Two accelerometers were placed on the opposite lateral sides of the sample into their central position. To allow attachment of the accelerometer to the input-signal side of the sample, custom-made steel adaptor with screw thread on one of its side was designed and glued by two-component superglue X60 to the input-signal side of the sample and to the speaker (Fig. 1).

Fig. 1. Accelerometers attachment: steel adaptor with screw thread and exciting speaker.

Acoustic signal represented by one period of sine wave of the frequency 1000 Hz and 4000 Hz was generated by GW Instek AFG-3051 arbitrary waveform generator, amplified by Power Dynamics PDV240Z amplifier and induced to the sample by a commercially manufactured surface speaker. The input vibration sensing accelerometer was mounted to the screw-thread placed in the inner side of the adaptor and the output sensing vibrations accelerometer was mounted to the opposite side of the sample. Both, input and output signal were monitored by piezoelectric accelerometers PCB Piezotronics M352C66 that were connected by a coaxial cable to supporting datalogger PCB Piezotronics 482C, logged by GW Instek GDS-2104A oscilloscope and analysed by DIADEM software.

The second experiment was based on the acoustic pressure level measurements in the designed reverberation chambers (Fig. 2). The principle of the measurement is similar to the experiments carried out in large-scale [12]. Two shells of 20 mm width and $(500 \times 390 \times 400) \text{ mm}^3$ outer dimensions were made from the high-performance concrete and polyurethane acoustic insulation of 50 mm width was placed inside the skeleton, so that inner dimensions of the shells were of $(360 \times 250 \times 330) \text{ mm}^3$. One chamber was fitted by a speaker and two precise PCB 378B02 microphones were installed into both chambers for the acoustic pressure level monitoring.

Fig. 2. Reverberation chambers designed for measurements of acoustic properties of brick blocks.

Brick block produced by Heluz company was wrapped by concrete in the designed mould to align the sample to a correct position between the reverberation chambers (Fig. 3). After hardening of the concrete shell, the brick block-concrete sample was placed in between the chambers and tightened to avoid acoustic losses.

Fig. 3. Brick block testing sample produced by Heluz company.

Finally, acoustic signal was generated by GW Instek AFG-3051 arbitrary function generator and amplified by Power Dynamics PDV240Z amplifier. The acoustic pressure level was monitored in time domain by 4-channel vibration analyser Adash A4404 SAB (1/3 octave resolution) with a supporting computer (Fig. 4). Power on the speaker was monitored by GW Instek GPM-8213 wattmeter and kept on (10.10 ± 0.01) W for all the tested frequencies.

Fig. 4. Equipment for the acoustic pressure level measurements in reverberation chambers.

3 Results and Discussion

Within the transmitter-receiver experiment, steel sample was subjected to excitation by one period of sine wave with frequency of 1000 Hz and 4000 Hz. In Fig. 5 and Fig. 6, voltage response on the accelerometers is presented. Time difference between the initial increase of the input and output accelerometer amplitudes was used for calculation of the sound velocity. Propagation of the period of acoustic wave through the sample lasted 4.56×10^{-5} s (1000 Hz) and 4.62×10^{-5} s (4000 Hz), so the calculated velocity of the sound waves were of $4951.8 \text{ m} \cdot \text{s}^{-1}$ and $4887.4 \text{ m} \cdot \text{s}^{-1}$, respectively.

Fig. 5. Voltage response (1 sine wave, 1000 Hz) on accelerometers – steel sample.

Fig. 6. Voltage response (1 sine wave, 4000 Hz) on accelerometers – steel sample.

Within the experiment based on measurements in reverberation chambers, the ratio of the acoustic pressure level was calculated for the monitored frequencies (Fig. 7). The lowest attenuation of 0.57 – 0.69 was observed for low frequencies (50 Hz, 63 Hz, 80 Hz, 100 Hz), whereas the highest attenuation, that was lower than 0.4, for middle frequencies (630 Hz, 1250 Hz, 4000 Hz, and 6300 Hz) and high frequencies (16 000 Hz, 20 000 Hz).

Fig. 7. Acoustic pressure level ratio dependence on the frequency - brick block.

4 Conclusions

In this paper, two types of acoustic measurements were presented together with examples of measurements conducted on two materials widely used in the building industry. Within the first measurement, steel prism was embedded by two accelerometers. One accelerometer was used for monitoring of a defined acoustic signal (one period of the sine wave) entering one lateral side of the sample, whereas the second accelerometer for monitoring of the signal that passed through the sample. Time delay between these two signals was used for calculation of the sound wave velocity through the material. Calculated sound wave velocities ($4951.8 \text{ m}\cdot\text{s}^{-1}$ - 1000 Hz, $4887.4 \text{ m}\cdot\text{s}^{-1}$ - 4000 Hz) were in good agreement with tabulated data. Such results are important input parameters for mechanical models that are used for prediction of acoustic behaviour of the materials.

The second type of measurement was based on determination of the acoustic pressure level of sound sine wave of defined frequency in reverberation chamber with the speaker and the acoustic pressure level in the second chamber where the sound waves are attenuated by propagation through the sample. Calculated acoustic pressure level ratio was highest for 63 Hz (0.69) and lowest for 16 000 Hz (0.36). However, in some other frequency bands was also observed ratio lower than 0.4 (200 Hz, 630 Hz, 1250 Hz, 4000 Hz, 6300 Hz, 20 000 Hz). Such indicator can be used for comparison of acoustic insulation ability of similar construction elements, such as brick blocks with different geometrical system of the voids and various types of bulk fillers used in the voids for acoustic waves scattering.

This research has been supported by the Ministry of Industry and Trade of the Czech Republic, under Project No. FV10036.

References

1. M. Oh, K. Shin, K. Kim, J. Shin, *Sci Total Environ* **651**, 1867-1876 (2019)
2. J. S. Christensen, O. Raaschou-Nielsen, A. Tjønneland, R. B. Nordsborg, S. S. Jensen, T. I. A. Sørensen, M. Sørensen, *Environ Res* **143**, 154-161 (2015)
3. M. Sørensen, Z. J. Andersen, R. B. Nordsborg, T. Becker, A. Tjønneland, K. Overvad, O. Raaschou-Nielsen, *Environ Health Persp* **121**, 217-222 (2013)

4. K. M. Paiva, M. R. A. Cardoso, P. H. T. Zannin, *Sci Total Environ* **650**, 978-986 (2019)
5. A. Binal, *B Eng Geol Environ*, **77**, 815-822 (2018)
6. D. Colakkadioglu, M. Yucel, B. Kahveci, O. Aydinol, *Environ Monit Assess* **190**, (2018)
7. M. A. Barcelo, D. Varga, A. Tobias, J. Diaz, C. Linares, M. Saez, *Environ Res* **147**, 193-206 (2016)
8. S. Schiavoni, F. D'Alessandro, F. Bianchi, F. Asdrubali, *Renew Sus Energ Rev* **62**, 988-1011 (2016)
9. F. Asdrubali, F. D'Alessandro, S. Schiavoni, *Sustainable Mater Technol* **4**, 1-17 (2015)
10. L. Fiala, J. Vyborny, M. Dolezelova, E. Vejmelkova, R. Cerny, *AIP Conference Proceedings 1988*, 020014 (2018)
11. V. Marcantonio, D. Monarca, A. Colantoni, M. Cecchini, *Mechanical Systems and Signal Processing* **120**, 32-42 (2019)
12. E. Fraile-Garcia, J. Ferreiro-Cabello, B. Defez, G. Peris-Fajanes, *Materials* **9** (2016)