Flanking sound transmission in an innovative lightweight clay block building system with an integrated insulation used at multifamily houses

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ABSTRACT

Accurate calculations in building acoustics depend amongst other on matching values of the vibration reduction index k_{ij} in component nodes. The usage of common calculation methods based on the mass-ratio of homogeneous materials may fail in complex wall and ceiling structures, so measurements of the values are necessary. In this paper, a comprehensive experimental determination and analysis of the vibration reduction index according to EN ISO 10848-1 on an innovative lightweight clay block building system with integrated thermal insulation is presented. For this purpose, a mock-up consisting of 3 rooms at 2 floors was created in real-size according to the standardized specifications. Investigation shows, that on the one hand, the increased inner damping due to the integrated thermal insulation and on the other hand, modal phenomena in the low-frequency range can cause problems by determining the necessary vibration level differences. To get reliable results, comprehensive analysis on the masonry are performed. A combination of experimental modal analysis and computer-based FEM-simulation models allows a deep insight into the resonant behavior of the entire wall structures, as well as the individual brick. It is shown that the positioning of the measurement positions possibly can have strong effects on the resulting values.

Keywords: Sound, Insulation, Vibration, Measurement, Simulation

1. INTRODUCTION

Calculations of the acoustic behavior of building structures are based amongst others in the international standard series EN ISO 12354 (1), which allows calculations of the sound transmission also inside multifamily houses. In these standards, a model is used, which can be preferably applied to massive, homogeneous constructions. The resulting sound power in the receiving room is determined by the radiated sound from the separating component and the adjacent component. The total transmittance is thereby associated with the transmission factors of the different components and systems.

The junctions of the structures are specified by the so-called “flanking sound reduction index”. To calculate this parameter the so called “vibration reduction index k_{ij}“ needs to be determined by special measurements. The corresponding measuring methods are anchored in the international standard series EN ISO 10848 (2). The excitation of the components is carried out with airborne sound or structure-borne sound. The latter allows the usage of transient or stationary signals for the excitation and detection by piezo transducers before and behind the junction.

Choosing a structure-borne noise excitation, however, some significant aspects have to be considered. An essential condition for further calculations is a diffuse sound field of the components. This can be ensured by sufficient modal density and high modal overlap factors. Furthermore if an extra attenuation with distance due to high internal damping – also called the “element attenuation” (dB/m) – is recognized, the vibration field may are not supposed to be diffuse (2).

Lightweight constructions are frequently inhomogeneous structures, therefore the physical circumstances may reach different limitations of applicability of currently valid standards. This aspect is analyzed in extensive investigations (4,5,6).

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New innovative designs of clay block building systems in some cases also will not meet the scope of the above mentioned current standards under certain circumstances. In this paper, an innovative clay block building system, filled with mineral wool is investigated comprehensively. Caused by internal losses, modal effects, thickness vibrations and other effects it can be assumed, that this system is a good example for not meeting the current standard scope. The individual brick is analyzed, as well as its interaction as part of a whole brickwork within a special mockup. Although there are indicated rough conditions concerning the selection of measurement positions, it becomes apparent that the distribution of the measurement positions can have distinctive consequences for the measurement results of such building systems.

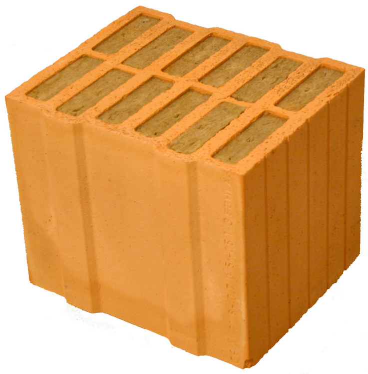

Figure 1 – Innovative lightweight clay block with integrated thermal insulation

2. REAL SIZE MOCK-UP AND MEASUREMENT METHOD

A real size mock-up was designed and built up in compliance with the standard requirements to determine the vibration reduction index k_{ij} and to perform additional specific investigations. The exterior walls of the three rooms consist of bricks with a thickness of 25 cm and 30 cm of the same type as former described, with an interior plaster with a thickness of 15 mm. The partition wall consists of an alternative 25 cm thick brickwork, with a 15 mm thick plaster on both sides, which has a significant increased mass per unit area related to the exterior walls. The separating floor consists of 18 cm reinforced concrete.

Figure 2 – Mock-up

The fundamental measurement method for the determination of the vibration reduction index k_{ij} is shown in Figure 3. One of the participating walls is excited by an electrodynamic shaker and the velocity level is detected by piezo transducers on the source and receiving side. The resulting velocity level difference can be determined. The vibration reduction index is determined by performing and averaging the measurements in both directions. The calculations also include other parameters like the structure-borne reverberation time.

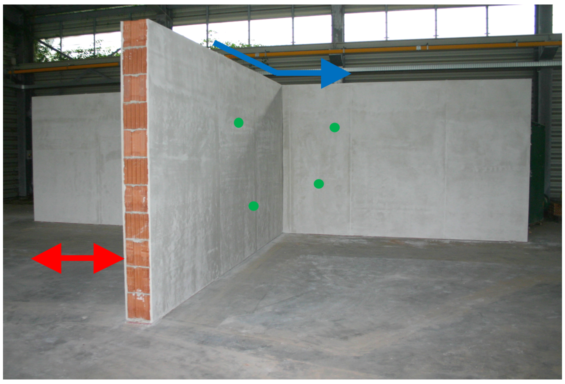

Figure 3 – T-junction of brickwork / measurement procedure: excitation of the wall by an electrodynamic shaker (**red**); determination of the velocity level by piezo transducer (**green**) to get the measurement values for the velocity level difference due to the junction (**blue**)

3. ADDITIONAL ANALYSIS, RESULTS AND DISCUSSION

3.1 Investigations concerning the element attenuation

One of the essential boundary conditions to determine the vibration reduction index according to (2) is a maximum spatially decaying vibration level of 6 dB along the entire used measurement area. Though (2) does not contain detailed approaches how to prove this fact either by calculation or measurement. In the present case, this represents a significant factor, since the internal damping at high frequencies causes an overestimated final value (k_{ij}), if measurement positions outside the permissible measuring area are included in the calculation. Subsequently calculations of minimum standards in sound insulation may be falsified.

To determine the element attenuation the velocity levels were detected by sensors at a distance of 5 cm along predefined horizontal and vertical measurement paths. The wall was excited by a shaker at the exterior side at a distance of 0.5 m from the junction. In (4) there is mentioned an alternative in-plane excitation across the junction by positioning the shaker on an adjacent wall instead of such a point excitation. Latter was chosen due to a sufficient SNR, and the fact that this type of excitation is also used in the measurements for the vibration reduction index. Figure 4 shows such a measurement path and some fixed transducers.

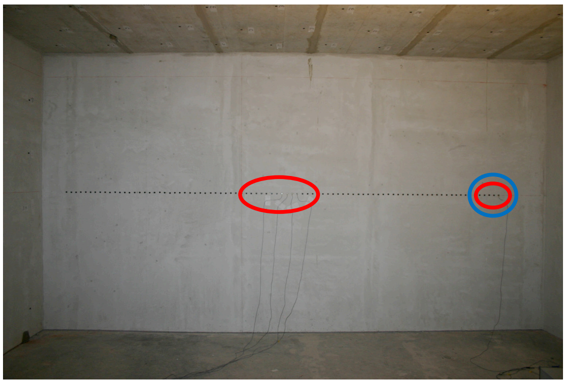

Figure 4 – Determination of the element attenuation by piezo transducers (**red**), excitation on the exterior side by a shaker (**blue**)

The following figures show the obtained results: In Figure 5 (left) additional near-field components of the propagating wave up to 1 m increase the vibration level difference. Usually these components are decaying exponentially (7), for a better illustration it was chosen a linear trendline. After they are decayed, a uniform decrease in vibration level sets with distance, which is strongly frequency dependent (Figure 5, right).

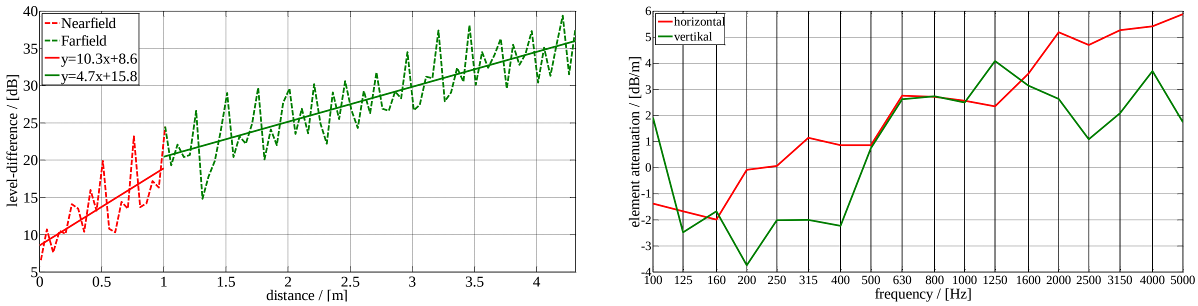

Figure 5 – Velocity level differences along the horizontal measuring path at 2500 Hz (left), element attenuation due to the internal damping (right)

This circumstance is due to several effects, which are obvious visible especially in a horizontal measurement shown in Figure 6 (left): In the low-frequency range up to 500 Hz strong modal phenomena cause a very low (modal) damping. At the highest frequency used to determine the vibration reduction index (1250 Hz), a significant element attenuation of 2.4 dB/m appears (grade of the trendline), which results in a usable measurement range of about 2.5 m, according to the maximal element attenuation of 6 dB. The element attenuation increases with the frequency, which is primary due to the filling with mineral wool. At a frequency of 5000 Hz there ensues a high value of 5.88 dB/m.

The high offset of the curves of the horizontal measurements may cause due to the following assumption: For this path the excitation point was 0.5 m far away from the junction (clamped boundary), so some frequencies in the lower range are less excited than higher frequencies. The excitation point on the vertical path was about 8 cm far away from an almost free-vibrating boundary (elastic support of the wall), so the frequency spectrum is excited more consistent. However, this assumption was not further investigated.

The measurement was carried out in the same way in vertical direction, the results are shown in Figure 6 (right). For a better comparability with the horizontal measurement, the diagram has been extended to the higher path length of the horizontal measurement. In the low-frequency range it indicates an apparent negative level difference. This is also obvious in other frequency ranges in Figure 5 (right). However, this is due to the (in comparison to the long wavelength of the bending waves) short path length of the measurement because of the limited height. This results in an incorrect fit of the trendline. The other curves are very close to each other, which is due to the fact that in comparison to the horizontal measurement, no fillets have to be bridged. At 1250 Hz it is shown a maximum damping of about 4.09 dB/m, resulting in an usable measurement area of only about 1.47 m.

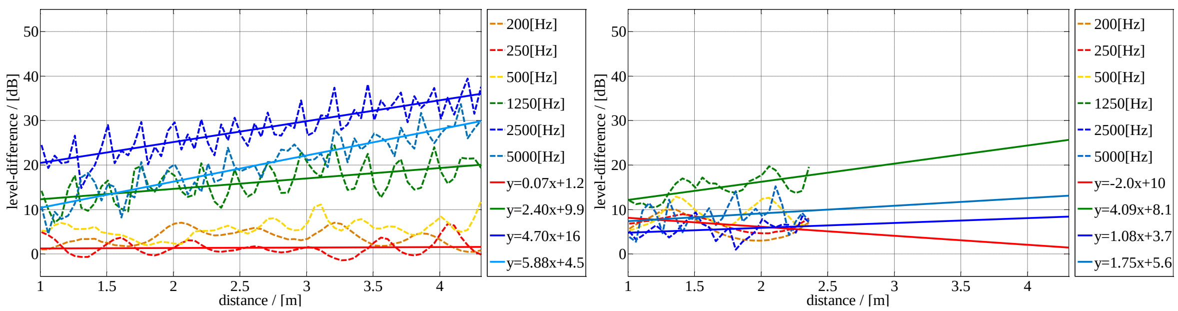

Figure 6 – Velocity level difference at different frequencies, horizontal (left) and vertical (right)

Further investigations showed, that an inclusion of measurement positions outside of these reduced measurement areas may cause in an increasing (single value) vibration reduction index up to 6-7 dB (depending on the number of included positions and their distance from the junction).

3.2 Investigations concerning modal phenomena

To get a first impression of the resonant behavior of the individual brick, extensive FEM-simulations were performed. Here, the modal behavior could be determined. The investigations show that the cavities - filled with mineral wool - and the plate structures resulting from the solid brick cause obvious resonant behavior in the range of 1600 Hz to 2500 Hz. This aspect is illustrated in the following Figure 7. Since the filling has only minimal influence on the position of the modes in the frequency spectrum, the wool could be removed to get a more descriptive representation.

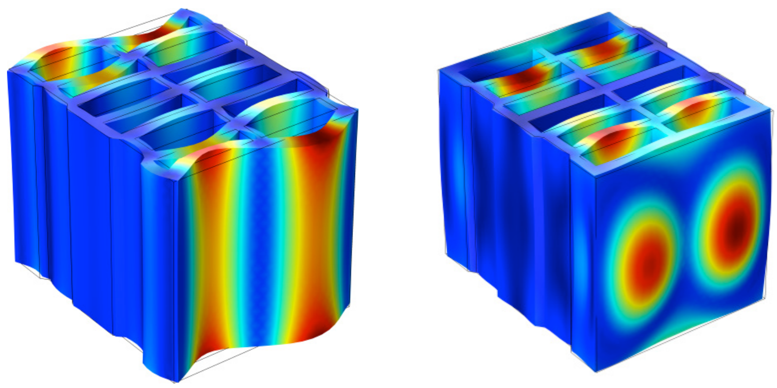

Figure 7 – Various mode shapes between 1600 Hz and 2500 Hz

These mode shapes cause an increased emission of sound energy in the considered frequency range. Although only frequencies in the range of 200 Hz up to 1250 Hz are taken into account in the calculation of the single value of the vibration reduction index, such effects should be considered when using the frequency-dependent values ((2) requires a measurement range from 100 Hz up to 5000 Hz).

In the previous subchapter measurements and simulation models have been described to investigate the effects of mineral wool, especially in terms of the element attenuation. Figure 7 (left) showed that the low frequency range may be dominated by distinctive boundary waves with a very low damping. This leads to the conclusion that the single bricks and their internal structure are not in prime concern in this frequency range, but here the wall has to be regarded approximately as a vibrating plate. This aspect could be confirmed in the course of further FEM-simulation results. One numeric result is shown in Figure 8, where the vibration of the wall results in a mode shape at about 95.4 Hz.

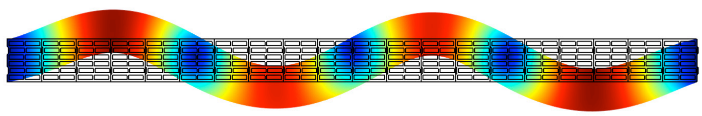

Figure 8 – FEM-Simulation of a wall: mode shape at 95.4 Hz

Due to the relative low mass per unit area of the wall construction of about 231 kg/m², calculations prior to the measurements according to (3) showed that a low modal density should be expected. As a consequence, one of the most important boundary conditions - a diffuse vibration field - may not be fulfilled in the lowest frequency range. To investigate this aspect, experimental modal analysis were performed along horizontal and vertical pre-defined paths. The wall was excited at discrete points with a distance of 10 cm by an impulse hammer and the acceleration was detected at a fixed sensor position. The resulting transfer functions were assembled to determine the mode shapes.

The following Figure 9 shows one of these measurements along a horizontal path in a waterfall diagram. Especially in the lower frequency ranges some distinctive mode shapes can be recognized.

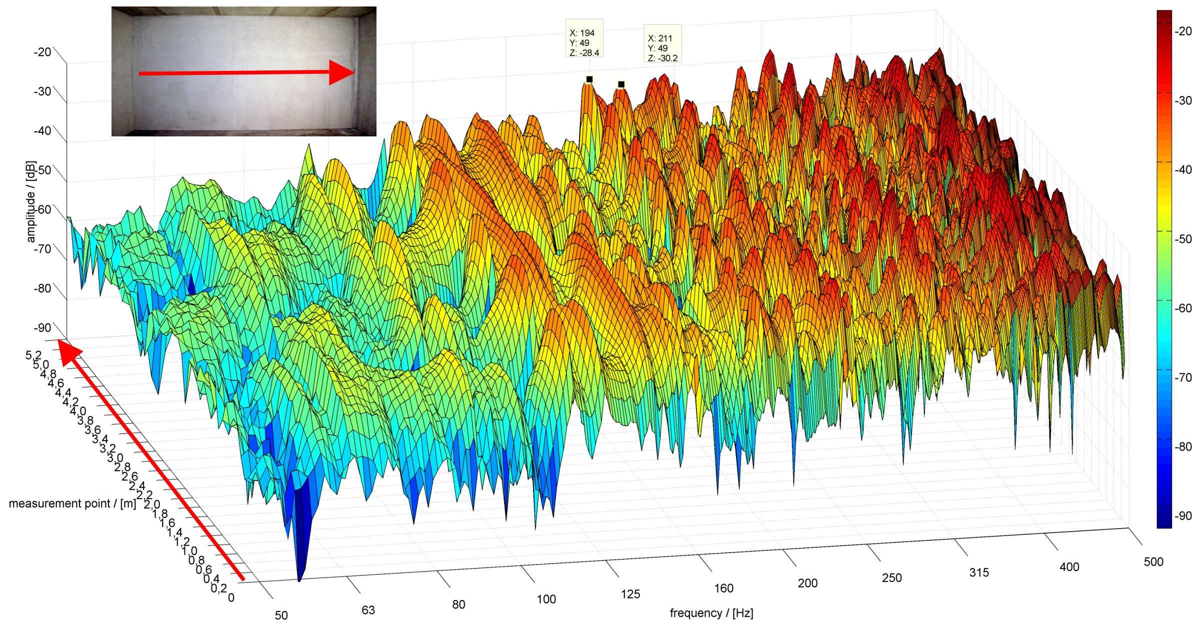

Figure 9 – Mode shapes of the entire wall on a horizontal measurement path

To determine the number of modes and the modal overlap factor, an alternative illustration in Figure 10 is chosen. Here the frequency ranges are shown, which are generally used for averaging the third-octave bands at center frequencies of 200 Hz and 250 Hz. These frequencies are the lowest ones, which are also used to calculate the single-value of the vibration reduction index. The figures obvious confirm the assumption of a low modal density and a poor modal overlap factor.

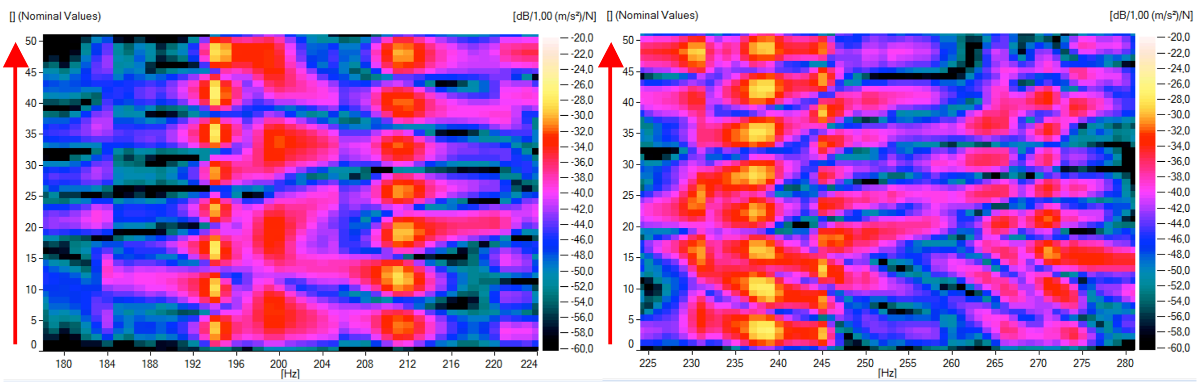

Figure 10 – Various ranges of mode shapes of the entire wall on a horizontal measurement path

Such modal phenomena can cause heavily fluctuating measurement values (velocity level differences), where even negative ones may be detected (positioning of the sensor on the transmission side near a wave node and on the receiving side near an antinode). In such a case, the standard (2) requires an increasing of the number of measuring positions according to clearly defined calculation methods. The measurement standard (2) also requires a minimum distance between single measurement positions of 0.5 m. Obviously this approach may cause problems to get reliable measurement results due to the already highly reduced measurement area caused by the high element attenuation.

4. CONCLUSIONS

The calculation model for sound transmission between rooms in the series of standards EN ISO 12354 (1), which is based on a simplified statistical energy analysis (SEA), assumes diffuse sound fields for the calculations. At inhomogeneous, complex building components such as used for example in lightweight constructions, this assumption will not hold true, since element attenuation and modal phenomena can play an important role. This can cause problems especially in the determination of required calculation parameter e.g. the vibration reduction index by measurements.

The present work deals with these aspects by means of a correct acquisition of the required parameters for a reliable sound insulation calculation model. Many different physical effects were already observed. It becomes apparent that an inappropriate choice of measurement positions can have a significant influence on the final value of the vibration reduction index k_{ij} under the prevailing circumstances.

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