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Zaretskyi, Vladyslav; Bida, Dmytro

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Vladyslav Zaretskyi,
Dmytro Bida

RESEARCH OF SOUND INSULATION FREQUENCY RESPONSE FOR A MULTILAYER INHOMOGENEOUS WALL STRUCTURES

The object of research is the amplitude-frequency characteristic of sound insulation of multi-layer heterogeneous structures. One of the most problematic places is the calculation methodology, due to the existence of standards such as ISO, DBN, which have some differences between them, and software, the calculation methodology of which is not fully known, due to the copyright of the latter.

Using the modeling method in the INSUL software complex, the amplitude-frequency characteristics of the sound insulation of the partition walls between the halls were obtained. On-site measurements were carried out on a real object identical to the simulated fence constructions presented by the MULTIPLEX cinema in the DAFI shopping center in Dnipro (Ukraine). The calculation methodology of the INSUL software is completely unknown. According to information from open sources, it can be concluded that linear modeling of the amplitude-frequency characteristic is used. The measurements were carried out according to DBN B.1.1-31:2013. Data obtained theoretically, during modeling, and experimentally are compared with each other. The expediency of taking into account the results obtained with the help of the INSUL software when writing a new methodology for the state standard or for improving the latter is considered. Comparing real and simulated amplitude-frequency characteristics, it is possible to conclude that the INSUL software complex is not accurate at high frequencies. This phenomenon may be related to the inherent resonances of the existing partition, or to the quality of the installation, which can be equated to a setup error, due to the lack of possibility of influencing the quality of the construction process of the measurement object. A possible error occurs when the soundproof partition is violently connected to the existing structures of the building, or due to the presence of resonating technical elements in the cinema hall (air ducts, metal structures of the stage and seats, etc.). This error is not influential due to the not significantly small wavelength in the frequency of 3000–8000 Hz. Therefore, as a conclusion, the INSUL software can be used in the development of the methodology of state standards for sound insulation in buildings.

Keywords: *soundproofing, soundisolation, building regulations, architectural acoustics, building acoustics, building structures, soundproofing structures.*

1. Introduction

In the modern world, the acoustic comfort of a room is an integral part of the design of office, industrial and residential premises. But due to the density of buildings, the high cost of the territory and other restrictions, it is necessary to reduce the thickness of the partitions and their mass while maintaining the same efficiency of noise and sound insulation. This problem can be noticed when designing real objects. Engineers, builders and designers, most often at the request of the customer, plant materials that are not suitable for the purpose of saving on the implementation process. The authors, while preparing sections «noise protection» for commercial objects, have repeatedly encountered the replacement of materials with worse sound insulation indexes. This is due to the low competence of the construction site control authorities in matters of architectural acoustics. Projects, in the absence of the «noise protection» section, are accepted with known errors, which lead to incorrect implementation at the construction stage. This negligence in architectural design leads to additional costs to solve the problem of sound insulation, after the completion of construction work and putting the facility into operation.

Example, in the existing Ukrainian standards for today there are only two options for calculating sound insulation for:

– Insulation with massive acoustically homogeneous materials (brick, aerated concrete) – has a high sound insulation index, but at the same time a large thickness.

– Insulation with multilayer structures such as two layers of sheet material (gypsum plasterboard, gypsum fiber, wood fiber or chipboard) on the frame, with an air gap between them – it has a small thickness, but is significantly inferior to massive structures in sound-proofing properties.

However, there is a third option, to use a combination of sheet and massive homogeneous materials.

But there are no recommendations for the theoretical calculation of sound insulation of these types of structures.

For this purpose, this work is to understand how much more justified is the use of the latter type of structures and to identify key tasks for compilation of a unified methodology for calculating these structures.

Thus, *the object of research* was the amplitude-frequency characteristic of sound insulation of multi-layer heterogeneous structures, due to their most frequent use as the main structural building elements.

The aim of research is to study the characteristics and methods for calculating the sound insulation of building structures in order to find the optimal calculation method.

2. Research methodology

2.1. Well-known solutions of structures used in Ukraine in construction according to Ukrainian standards and [1]

2.1.1. Brick wall. The single-layer construction is made of a brick with a density of 1600 kg/m^3, standard thicknesses are taken from [2] given in Table 1. The sound insulation frequency response for a single-layer brick construction is given in Fig. 1.

Table 1
Sound insulation indexes of single layer brick construction in standard thickness

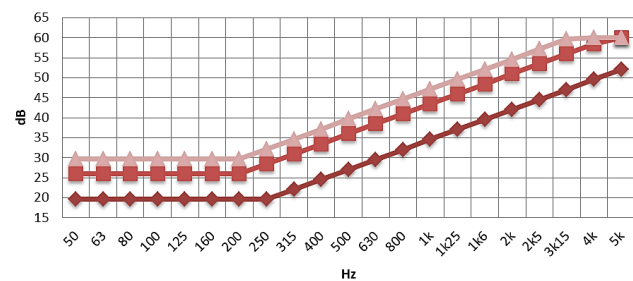| Thickness, mm	Insulation index, dB
125	46
250	52
375	55
500	58
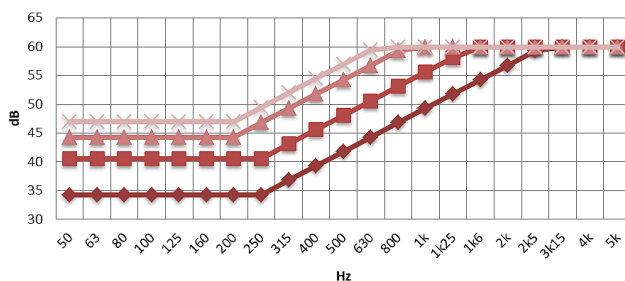
Fig. 1. Sound insulation frequency response for a brick wall with different thicknesses: — 125 mm; — 250 mm; — 375 mm; — 500 mm

2.1.2. Wall of aerated concrete block. The single-layer construction is made of the aerated concrete block with a density of 400, 600, 800 kg/m^3, standard thicknesses are taken from [3] given in Table 2.

The sound insulation frequency response for a single-layer brick constructions are given in Fig. 2–4.

Table 2
Sound insulation indexes of aerated concrete construction in standard densities and thickness

Density, kg/m^3	Thickness, mm	Insulation index, dB
400	100	32
	200	40
	300	44
600	100	35
	200	44
	300	47
800	100	38
	200	46
	300	50

Fig. 2. Sound insulation frequency response for aerated concrete walls with density 400 kg/m^3 and different thicknesses: — 100 mm; — 200 mm; — 300 mm
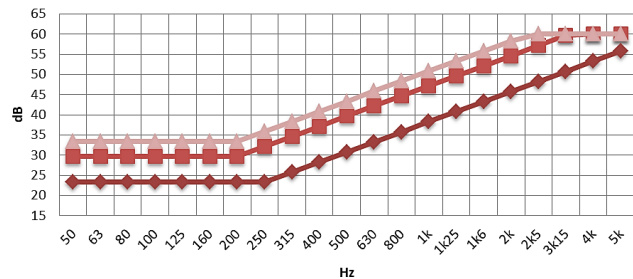
Fig. 3. Sound insulation frequency response for aerated concrete walls with density 600 kg/m^3 and different thicknesses: — 100 mm; — 200 mm; — 300 mm
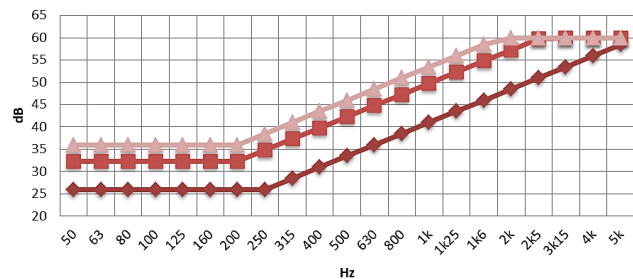
Fig. 4. Sound insulation frequency response for aerated concrete walls with density 800 kg/m^3 and different thicknesses: — 100 mm; — 200 mm; — 300 mm

2.1.3. Gypsum wall with a layer. Two-layer construction such as two sheets of drywall, mineral wool, two sheets of drywall, taken from calculates based on [4].

Sheets of gypsum board with a density of 830 kg/m^3 and a thickness of 12.5 mm.

Mineral wool with a thickness of 100 mm and a density of 40 kg/m^3.

2.2. Solutions of structures used in Ukraine, but not taken into account in DSTU

2.2.1. Brick wall using gypsum plasterboard. The multilayered design model from [5] at the basis of which the brick wall to which two sheets of gypsum cardboard fasten on a profile is used, between them mineral wool is put.

Profiles of different sizes are used (mainly used 100 mm profile). The ratio of the profile to the sound insulation index is shown in Table 3 [6].

Sound insulation indexes of multi layer construction with metal profiles in standard thickness

Thickness, mm	Insulation index, dB
125	59
250	65
375	71
500	74

2.2.2. Wall of aerated concrete block gypsum plasterboard. Multilayer construction, based on which an aerated concrete wall of different density is used (mainly with density 600 kg/m^3) [7], to which two sheets of gypsum board are attached, between which mineral wool is placed.

Profiles of different sizes are used (mainly used 100 mm profile). The ratio of the profile to the sound insulation index taken from calculates based on [4] and shown in Table 4 (only for density 600 kg/m^3).

Sound insulation indexes of aerated concrete with metal profile in standard densities and thickness

Density, kg/m^3	Thickness, mm	Insulation index, dB
400	100	46
	200	50
	300	53
600	100	51
	200	55
	300	58
800	100	54
	200	58
	300	61

2.3. INSUL. The data presented in Tables 3 and 4 were obtained using the software package INSUL. INSUL is a program for predicting the sound insulation of walls, floors, roofs, ceilings and windows. According to [5] program can accurately estimate the predicted levels of air and shock noise reduction within the octave and 1/3 octave scales. Also calculate the sound insulation index of airborne noise.

As for predicting the frequency response of sound insulation of walls, this software has the ability to present the results not only of single-layer and multilayer structures with the same types of material on the cladding, but also for multilayer structures with different types of materials.

However, due to the fact that this software product is not certified at the Ukrainian level, and cannot be the main tool for calculating the frequency response of sound insulation.

But using the data obtained by simulation, it is possible to use for comparison with experimental obtained figures.

On the basis of their comparison to determine the main patterns and features of the behavior of multilayer inhomogeneous structures. It will help to create a method of calculating the frequency response of sound insulation of multilayer structures. Which will help to create a method of calculating the frequency response of sound insulation of multilayer structures.

2.4. Description of the experiment

2.4.1. Characteristics of the room. The premises selected for measuring the sound insulation characteristics of the multilayer enclosing structure fully comply with the following:

– paragraph 5.2 of [8] «Requirements for premises for measuring the sound insulation of internal enclosing structures in kind»;

– paragraph 5.3 of [8] «Requirements for premises for measuring sound insulation in external conditions».

Paragraph 5.2:

– Test rooms for measuring the insulation of air and impact noise by internal enclosing structures in kind shall consist of two adjacent rooms horizontally or vertically, between which the structure under test is located.

– The volume of rooms of high and low levels should be not less than 25 m^3, and linear dimensions – not less than 2.3 m.

– To create a more diffuse sound field when measuring in kind, scattering elements should be used in the test rooms. The area of one element must be at least 1.5 m^2. The total area of the scattering elements is not less than 5 m^2. Scattering elements shall not shield the test structure.

– If in nature the test structure has a different surface area from the high and low level rooms, then a larger area of this structure should be from the high level side. The common area of the test structure for two rooms must be not less than 10 m^2.

Paragraph 5.3:

– For measurements of air noise insulation by external enclosing structures, one room is used – a low-level room. The volume of the room must be not less than 25 m^3, and its linear dimensions – not less than 2.3 m.

2.4.2. Characteristics of measuring equipment and technical means. As a transmission system, a regular sound system of the cinema hall was used in the mode of operation higher than the standard one. In Fig. 5 is the amplitude-frequency response of the sound system of the hall in the mode «7».
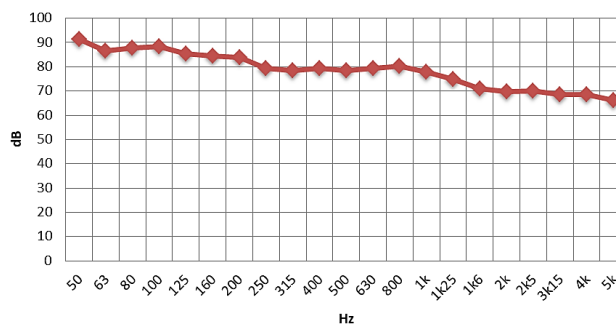

Fig. 5. Amplitude-frequency response of the sound system of the hall in the mode «7»

The receiving measuring system was a noise meter of the OKTAVA-110A (Fig. 6) model.

Fig. 6. OKTAVA 110A

Spectrum analyzer, portable vibrometer OKTAVA-110A is designed:

– to measure RMS, equivalent and peak sound levels, adjusted vibration acceleration levels, as well as octave and tertiary octave sound pressure levels and vibration acceleration;

– to assess the impact of sound on people in the workplace and in production;

– determination of acoustic characteristics of mechanisms and machines, as well as for scientific research. As stated in the [9] device is designed:

– for field and laboratory professional measurements of sound, infrasound, ultrasound, general and local vibration, vibration of buildings and machines;

– for frequency analysis of signals from various primary transducers (microphones, vibration sensors, pressure pulsation sensors, measuring and similar).

2.4.3. Measurement of airborne noise insulation. Based on the measurements conditions specified in the [10], the following conditions must be met.

Sound pressure levels in high and low rooms should be measured at least six points.

Measurement points (microphone locations) in high and low levels shall be evenly distributed over the volume, but shall not be less than 0.7 m from the surfaces of enclosures and 1.0 m from the test structure. The distance between the individual positions of the microphones must be not less than 0.7 m.

If a rotating microphone is used, its radius of rotation must be at least 0.7 m and the plane of rotation of the microphone must be inclined to the floor plane at an angle of about 10°.

The distance between the microphone and the loudspeaker in a high-level room must be at least 1.0 m [8].

Measurements should be made in third octave bands.

Measurements in octave frequency bands are allowed in full-scale conditions. The measurement should be performed in bands with geometric mean frequencies of 125, 250, 500, 1000, 2000 Hz.

2.4.4. Description of the test sample. As a test sample, it was decided to choose a fencing structure (Fig. 7) that separates the premises of the cinema hall and technical premises.

The enclosing structure has the following structure: a wall from the aerated concrete block with a density of 500 kg/m^3, basalt wool with a density of 40 kg/m^3, 2 layers of GCL sheets.

Aerated concrete Block 300mm,
Basalt wool 100mm
2xDrywall sheets 12,5mm
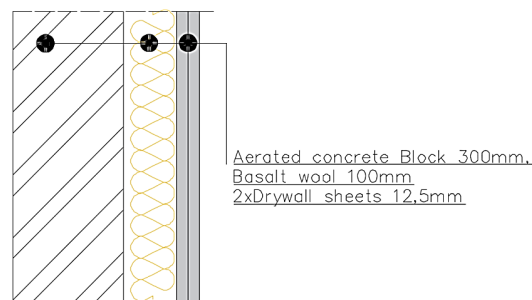
**Fig. 7.** Structure of a sample

3. Research results and discussion

To confirm the correctness of the theoretically calculated properties of multilayer wall structures, it was necessary to conduct a field experiment. For this purpose, the premises of one of the auditoriums of the MULTIPLEX cinema in the DAFI shopping mall in Dnipro (Ukraine) were chosen.

After obtaining the measurement results and their further processing, the following values of the frequency response of the sound insulation were obtained, presented in the form of a graph (Fig. 8).
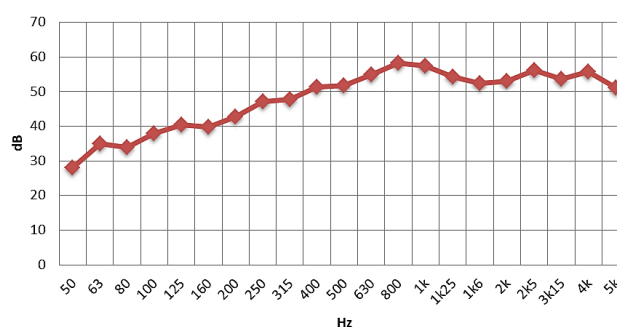

Fig. 8. Frequency response of the sound insulation of a sample

Next, a comparison was made with the values obtained by simulation in the software package INSUL (Fig. 9).

From the graph in Fig. 9 it is possible to see that in the medium-high frequency range there are some deviations between theoretical and experimental data.

This can be explained by non-ideal measurement conditions, as they were performed in real conditions, where it is not possible to exclude all possible acoustic interference.
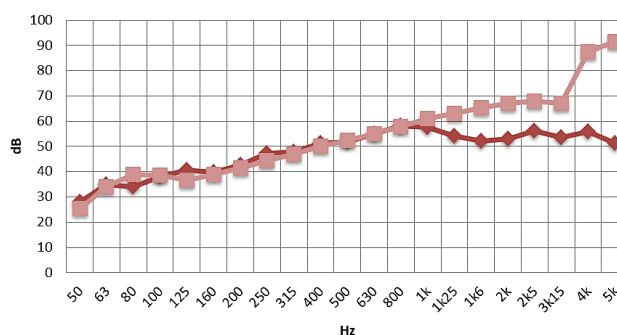
Fig. 9. Comparison between theoretical and experimental data:
♦ – Experiment; ■ – INSUL

But even now it is possible to see that to a greater extent the behavior of the frequency characteristics is the same, and this tells us that it is possible to rely on the

data obtained with the help of INSUL. With a sufficient number of experiments in ideal conditions, we can have every reason to write guidelines for calculating the frequency response of sound insulation of multilayer inhomogeneous structures, and making them in the state standard.

As it is possible to see from the theoretical data presented above, the use of multi-layer heterogeneous structures has a significant advantage over the structures available in Ukrainian standards, both in sound insulation and in saving usable space.

Also, in this work, we determined that the data that was obtained during modeling using the INSUL software package can be used as basic theoretical values when writing the methodology for calculating the sound insulation of multilayer heterogeneous structures.

Unfortunately, given the wide variety of solutions for building partitions (plywood sandwich panels, wooden partitions, and others). Due to less popularity, let's leave the question of calculating the sound insulation indices of such structures to an individual approach. In the future, let's continue to focus on general solutions that have and require more frequent use (homogeneous partition made of brick or aerated concrete, mineral wool, two sheets of gypsum).

The prospect of further research is to conduct a larger number of full-scale and laboratory experiments for the final study of the laws in calculating the sound insulation of multilayer structures, as well as writing a methodology for the state standard.

Due to economic problems around the world and urban congestion, it will be worthwhile to switch to cheaper materials, and, consequently, the sound insulation index will also be lower. This will lead to a deterioration in the quality of housing and facilities in general.

4. Conclusions

Analyzing the results obtained with the help of field measurements and simulations in the INSUL package, the results have excellent results in the high frequency range. This can happen for several reasons:
– Own resonance of the experimental partition.
– The quality of the installation of the partition.
– The presence of resonating technical elements (air ducts, metal structures of the stage and seats).

But this difference in results is leveled out due to the insignificantly small wavelength in the frequency of 3000–8000 Hz.

Based on the purpose of this work – to compare modern multi-layer constructions and outdated single-layer constructions, it is possible to see the advantages in the quantitative values of the sound insulation indices (on the example of a brick partition, Table 5).

These data show that it is more appropriate to use multi-layer structures because they can be used in a more compact form or to improve the results of existing homogeneous partitions.

Table 5

The quantitative values of the sound insulation indices of a brick partition

Thickness, mm	Single index, dB	Multilayer index, dB
125	46	59
250	52	65
375	55	71
500	58	74

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Vladyslav Zaretskyi, Postgraduate Student, Department of Electronics, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine, ORCID: http://orcid.org/0000-0003-4899-4545

✉*Dmytro Bida, Postgraduate Student, Department of Electronics, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Kyiv, Ukraine, e-mail: dm.v.beda@gmail.com, ORCID: http://orcid.org/0000-0001-5185-0927*

✉*Corresponding author*