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THEORETICAL AND EXPERIMENTAL PRINCIPLES OF DESIGNING SOUND INSULATION OF BUILDINGS AND STRUCTURE

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The principles of designing sound insulation of buildings and structures using materials of different physical characteristics are developed. The possibilities of simplifying sound insulation calculations for small values of the phase velocities of bending waves in the surface material are shown. It is shown that such a condition corresponds to small values of sound frequencies compared to the critical frequency of the surface. The limits of the acceptable error of calculations are determined, taking into account mainly resonant and inertial sound absorption. These limits roughly correspond to the sound frequencies $f < 0,5f_c$,$0,5f_c < f < 1,2f_c$ та $f > 1,2f_c$, f_c being the critical surface frequency of these mass and dimensional parameters. The mathematical functions for calculating the sound insulation of surfaces made of soft materials are obtained. The values of the response functions of surfaces of different sizes are determined. It is shown that for frequencies above 300–400 Hz, the response function approaches unity and can be ignored. This conclusion is confirmed by experimental data, which have an acceptable agreement with the calculations. This greatly simplifies the practical design of soundproof structures. The principles of designing a two-layer structure to improve sound insulation are determined. It was found that sound insulation increases with an increase in the gap between the surfaces. However, at distances greater than $7–8\cdot10^{-2}$ m, there is no increase in sound insulation, so an increase in the overall dimensions of soundproof structures is impractical.
Keywords: sound insulation, elastic modules, critical frequency, response function.

Introduction

In modern conditions, the acoustic load on urban environments is increasing. The sources of noise are traffic flows, civil aviation, technological equipment of urban infrastructure, etc. This calls for improved protection of people from noise exposure. One of the means of such protection is to improve the sound insulation of buildings and structures. This requirement is laid down in the European Directive on the reduction of risks to human health associated with noise exposure [1]. Noise-absorbing properties are inherent in some construction and cladding materials. But in many cases, they are either insufficient or excessive. This is largely due to the insufficient development of the mathematical apparatus for calculating the efficiency of a structure to provide sound insulation. Most of the analytical functions for sound absorption and sound insulation are somewhat abstract in nature, and are difficult to use in the practical design of soundproof structures. Some of the applied developments are outdated due to the consideration of materials that are not used or prohibited for use. In addition, the spectral composition of acoustic noise of man-made origin has changed in recent years. Therefore, an urgent task is to create a computational tool for designing soundproof structures of the required efficiency with the ability to optimise noise protection and verify the results of theoretical studies.

An overview of literary sources

A lot of attention is paid to the means of combating noise of anthropogenic origin due to the negative impact of noise on human health and complaints from the population [2, 3]. Most research in this area concerns the development of noise-absorbing materials. Paper [4] presents the results of the development of a metamaterial to reduce noise penetration through window openings. The efficiency of such coatings is high, but they are also very expensive. This paper does not provide a calculation justification for the required shielding coefficient (noise reduction indices). A number of composite materials have been developed to reduce noise levels [5, 6]. They provide high noise reduction indices for high frequencies, but are not effective enough for medium and low frequencies. A common disadvantage of all developed compositions is the difficulty of using them in the construction industry due to their high cost and low manufacturability, in particular, instability due to physical and chemical effects [7]. Recently, considerable attention has been paid to reducing the levels of low-frequency sound and infrasound [8, 9]. The specifics of protection against these factors are different physical absorption mechanisms compared to higher frequencies. All materials and structures for reducing infrasound and low-frequency noise levels are resonant. Therefore, it is desirable to harmonise the calculation tools for the design of low-frequency and high-frequency protective structures. This was partially done in the study [10], but the calculations and proposed design solutions are a combination of two protective structures, which is not always acceptable in practice. Most of the existing models for sound absorption are impedance-based and apply to porous materials [11]. However, real cladding materials have low porosity, so it is advisable to carry out calculations to determine the soundproofing properties of materials taking into account the elastic moduli and weight and size parameters of the materials. This will allow, if necessary, to optimise the protective properties of the structural design on the principles of reasonable sufficiency.

Presentation of the main material

The vibrations of any flat surface subjected to external mechanical action can be described by the equation of bending theory. In the one-dimensional case, the acoustic waves are assumed to be harmonic:

$$B\frac{\partial^4 u}{\partial x^4} - \omega^2 m u = \left(p_1 - p_2\right)_{z=0}, \tag{1}$$

where $u(x)$ is the surface deflection, B – is the cylindrical stiffness of the surface, m – is the surface mass (mass per unit area), ω is the cyclic vibration frequency, p_1, p_2 are the pressures on both sides of the surface.

At the same time:

$$B = \frac{Eh^2}{12(1-\sigma^2)}, \tag{2}$$

$m = \rho h$, where E – Young's modulus of the surface material, σ – Poisson's ratio, h – surface thickness, ρ – density of the surface material.

Thus, the equation of surface vibrations includes both the elastic moduli of the material and the mass and dimensional parameters.

The above equation is solved according to the standard procedure, which makes it possible to determine the deflection of the surface and the pressures on both sides of the surface.

If we assume the amplitude of the incident wave to be equal to unity, then the pressures in front of and behind the surface have the physical meaning of the coefficients of sound transmission and reflection from the surface.

In the process of calculations, it is important to take into account the case when the speed of wave propagation in the surface coincides with the speed of sound in the material. This occurs at a certain frequency, which is considered critical, and depends on the mass and dimensional parameters of the surface and the values of the elastic modules:

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{m}{B}}, \tag{3}$$

where c – sound speed in the surface material.

The sound insulation properties of surfaces against airborne noise in the case of a wave incidence at an angle of θ are characterised by the sound transmission coefficient $\tau(\theta)$ and sound insulation ($R = -10\lg\tau$):

$$\tau(\theta)=\frac{1}{1+\left(\frac{\omega m}{2\rho c}\cos\theta\right)^2\left(\frac{f^2}{f_c^2}\sin^4\theta-1\right)^2},\qquad(4)$$

$$R=10\lg\left[1+\left(\frac{\omega m}{2\rho c}\cos\theta\right)^2\left(1-\frac{f^2}{f_c^2}\sin^4\theta\right)\right],\qquad(5)$$

where ρc is the impedance of the wave propagation medium, ω is the cyclic frequency of the wave, m is the mass per unit surface area, f is the wave frequency, f_c is the critical frequency for the given conditions.

For frequencies at which $c_p << c$, where c_p is the phase velocity of bending wave propagation over the surface. The expressions for determining the sound transmission and sound insulation coefficients can be simplified:

$$\tau(\theta)=\frac{1}{\left(1+\frac{\omega m}{2\rho c}\cos\theta\right)^2},\qquad(6)$$

$$R=10\lg\left[1+\left(\frac{\omega m\cos\theta}{2\rho c}\right)^2\right],\qquad(7)$$

In fact, this corresponds to the condition $f^2 << f_c^2$. In practice, the above ratio can be used for $f < 0{,}5f_c$, because $(f^2/f_c^2\cos^4\theta)$ s reduced by the high degree of $\cos\theta$.

The analysis of formulas (4) and (5) shows that the dependence of R on the dimensionless parameter (f/f_c) and the angle of incidence is determined by only two parameters – the internal loss coefficient and the ratio of surface and medium impedances at the critical frequency.

Therefore, except in the case of $f < 0{,}5f_c$,the area near the critical frequency should be taken into account $f > f_c$, and practically $0{,}5f_c < f < 1{,}2f_c$. In this area, internal losses begin to become significant, due to the complex nature of the elastic modulus, as well as the parameter $f^2/f_c^2\cos^4\theta$. In the area $f > 1{,}2f_c$ the effects of wave coincidence begin to appear, due to the decrease in wavelength. In this case, due to interference phenomena, the sound insulation of a particular plane may differ in its individual parts. The criticality of this phenomenon must be determined on a case-by-case basis, depending on the required sound insulation value.

If the surface has low stiffness, which is typical for polymeric materials of small thickness, then the approaches to calculating sound insulation are different.Sound propagation through obstacles in soft materials has a number of peculiarities. The wave propagation speed in a membrane is constant at a constant tension [10]. The same applies to the speed of sound. In real structures, the sound speed of a material is significantly lower than the speed in free space ($c_m < c$). Based on this, it can be concluded that there is no wave coincidence phenomenon in a soft membrane coating. The degree of attenuation in such coatings is high, and the bending stiffness is low. Under such conditions, the contribution of inertial sound transmission increases. This is taken into account by introducing the response function F.

The sound insulation of such a structure is determined by the ratio:

$$R=10\lg\left(1+\frac{\pi^2}{\rho^2c^2}mf^2\frac{\cos^2\theta}{F^2}\right).\qquad(8)$$

The response function F is calculated rather complicatedly based on the weight and dimensions of the structure and the frequency characteristics of the sound. F values for different panel sizes are shown in Table 1.

As can be seen from Table 1, the response function is significant for frequencies of 300–400 Hz. At higher sound frequencies, the function can be considered equal to one.

The effectiveness of flexible structures of different sizes and surface densities is shown in Fig. 1.

Table 1

Values of the response function F for flat structures

Size $a \times b$, m^2	Frequency, Hz									
	50	100	150	200	250	300	400	500	800	1200
1,0×0,5	0,770	0,705	0,500	0,378	0,278	0,319	0,697	1,010	0,920	1,020
1,0×1,0	0,610	0,499	0,273	0,320	0,720	1,010	0,940	0,995	0,950	1,005
2,0×1,0	0,620	0,380	0,330	0,697	1,010	0,980	0,820	1,009	1,010	1,005

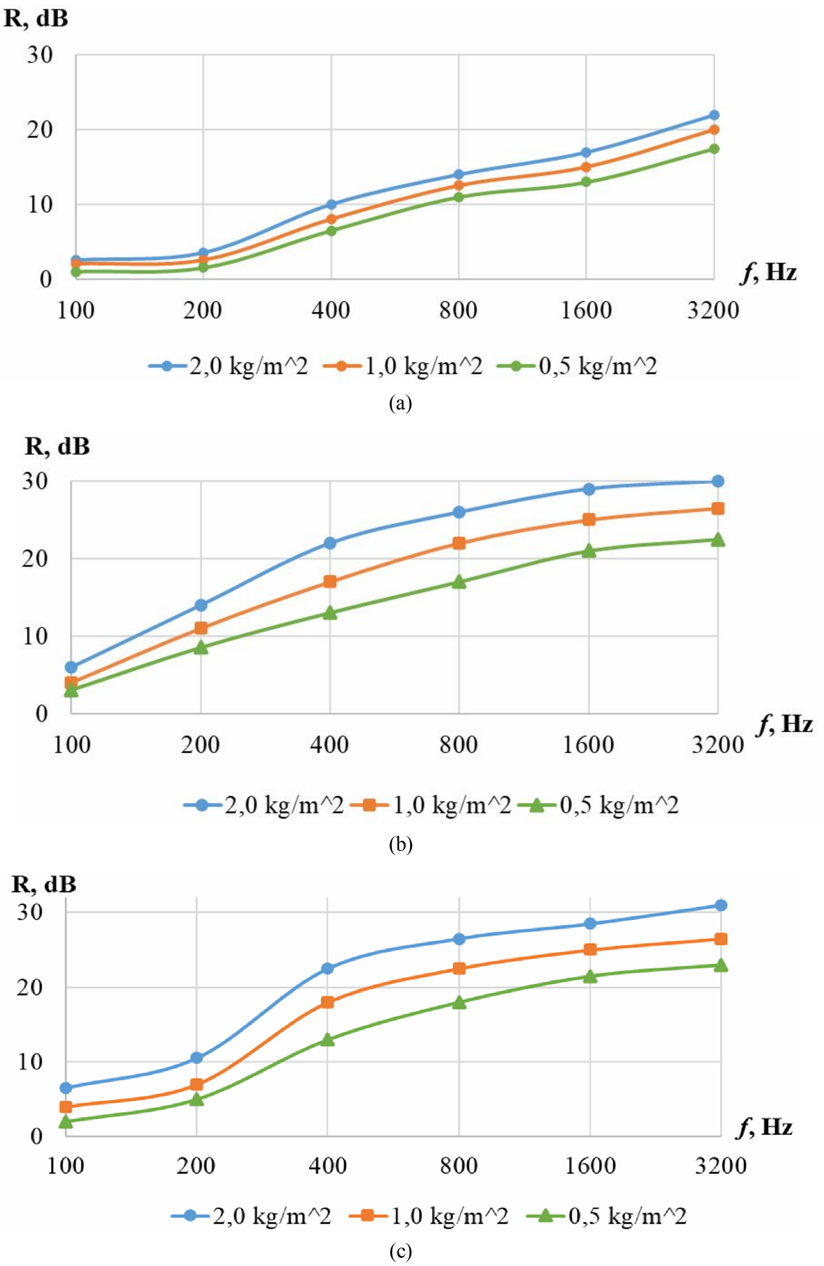

Fig. 1. Frequency dependences of the sound insulation efficiency of flat structures of different weight and dimensions: (a) – 1.0×0.5 m, (b) – 1.0×1.0 m, (c) – 2.0×1.0 m

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The data in Fig. 1 shows that the effectiveness of sound insulation depends on the surface density of the material and frequency. It is important to note that the sound insulation coefficient increases at sound frequencies above 300–400 Hz. There are slight fluctuations in the sound insulation coefficient that do not follow a regular pattern. This is a manifestation of the fluctuations in the response function given in Table 1. In general, there is a correlation between the calculated data in Table 1 and the experimental data shown in Fig. Therefore, it can be concluded that it is possible to use relations (4)–(7) in practical activities for the design of sound insulation of buildings and structures.

It is known that two-layer structures are more efficient. But calculations of their effectiveness for optimising sound insulation are complex and ambiguous. To determine the sound transmission coefficients, it is necessary to take into account the response function F_1 of the first surface on which the sound falls and the response function F_2 of the second surface on which the secondary sound falls. The F_2 function cannot be calculated unambiguously, so to assess the effectiveness of sound insulation, it is advisable to determine the resonant frequency of the two surfaces, which determines the quality factor of the entire oscillating system:

$$f_r = \frac{1}{2\pi}\sqrt{\frac{R(m_1+m_2)}{m_1 m_2}}, \tag{9}$$

where m_1, m_2 – mass per unit area of both surfaces, $R = \rho c^2/h$, ρ, c – air parameters in the gap between the surfaces of thickness h.

The average sound insulation of a two-layer structure can be determined by an approximate ratio:

$$R = 14\lg(m_1+m_2)+13+\Delta R, \tag{10}$$

where ΔR – contribution to sound insulation depending on the thickness of the air gap h.

For sound frequencies of 100–300 Hz, this value can be determined from the experimental data given in Table 2.

Table 2
The contribution of air gap thickness to sound insulation

h, 10^{-2}, m	ΔR, dB
2	1,0
4	3,0
6	5,0
8	6,0
10	6,4
12	6,7

That is, it can be concluded that air gaps larger than 7–8 cm do not actually increase sound insulation. At the same time, the overall size of the structure increases.

The use of two-layer structures is advisable in case of insufficient sound insulation with a single-layer coating. Sound insulation efficiency is predicted by calculation methods. The initial data are the amplitude-frequency characteristics of the noise to be reduced.

Porous materials are promising single-layer sound insulators. But designing soundproofing based on them faces a number of problems. The most important one is the lack of an easy-to-use mathematical apparatus. Even the use of the one-factor Delany-Bazley model is not always possible due to the presence of uncertain coefficients. In this case, it is necessary to experimentally measure the specific resistance to air flow of each material depending on its porosity. However, this way seems promising due to the high sound insulation efficiency obtained in experiments. To do this, it is necessary to simplify the calculation apparatus of the relevant models, taking into account the permissible calculation errors.

Conclusions

1. The basic functions for predicting the sound permeability and sound insulation of flat surfaces are determined. The relationship between the critical frequency of the surface and the surface density and elastic moduli of the surface material is shown. The possibility of simplifying the calculation of sound insulation under the conditions of small values of the phase velocity of bending waves in the material compared to the speed of sound in the medium is substantiated. It is shown that such a condition corresponds to small values of sound frequencies compared to the critical frequency.

2. The frequency bands of sound insulation calculations are determined, taking into account the predominant mechanisms of resonant and inertial sound absorption. They roughly correspond to frequencies less than $0{,}5f_c$, the interval from $0{,}5f_c$ to $1{,}2f_c$ and greater than $1{,}2f_c$. It is determined that at $f > 1{,}2f_c$ the effects of wave coincidence begin to appear, which is due to a decrease in the length of sound waves.

3. The mathematical functions for predicting the soundproofing properties of surfaces made of soft materials are obtained. It is shown that in this case the value of the surface response function should be taken into account. Calculations of the values of the response function for surfaces of different sizes are given. It is shown that for sound frequencies above 300–400 Hz, the value of the response function approaches unity. Therefore, it can be ignored in practical calculations. The obtained result coincides with the experimental data, which makes it possible to significantly simplify the calculations of sound insulation of flexible surfaces.

4. The principles of calculating the sound insulation efficiency of a two-layer structure are presented. It is shown that its value depends on the surface densities of materials and the distance between the surfaces. It is proved that the additional contribution to the sound insulation value of the gap between the surfaces is nonlinear. At values of the gap greater than $7–8\text{-}10^{-2}$ m, the sound insulation efficiency practically does not increase, which is a certain optimisation of the efficiency of the two-layer structure.

REFERENCES

1. Directive 2003/10/EC – noise. Of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (Seventeenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). European Agency for Safety and Health at Work. Latest update: 19/03/2021. URL: https://osha.europa.eu/en/legislation/directives/82
2. *Myshchenko, M. Pawlaczyk-Luszczynska, A. Dudarewicz, A. Bortkiewicz*. Health Risks Due to Co-Exposure to Noise and Respirable Crystalline Silica Among Workers in the Open-Pit Mining Industry—Results of a Preliminary Study. // Toxics 12(11), 2024: 781. https://doi.org/10.3390/toxics12110781
3. *Myshchenko, V. Nazarenko, A. Kolhanov, O. Malyshevska, M. Pohorilyi, L. Hrechukch, M. Ionda, O. Nykyforuk.* The content of acoustic signals and biological effects of noise in conditions of high level of work intensity. // Journal of Preventive Medicine and Hygiene.; 62(3), 2021: E763-E769. https://doi.org/10.15167/2421-4248/jpmh2021.62.3.1588
4. *Sanjay Kumar, Tiong Bang Xiang, HeowPueh* Lee. Ventilated acoustic metamaterial window panels for simultaneous noise shielding and air circulation, // Applied Acoustics, Vol. 159, 2020, https://doi.org/10.1016/j.apacoust.2019.107088
5. *Jayamani, M.K.B. Bakri*. Lignocellulosic fibres reinforced polymer composites for acoustical applications. // In: Kalia, S. (ed.) Lignocellulosic Composite Materials, pp. 415-444. Springer, Ber- lin (2018)
6. *U. Berardi, G. Iannace.* Predicting the sound absorption of natural materials: best-fit inverse laws for the acoustic impedance and the propagation constant. // Appl. Acoust. 115, (2017), 131-138
7. *Liang, M., Wu, H., Liu, J. et al.*Improved sound absorption performance of synthetic fiber materials for industrial noise reduction: a review. // J Porous Mater 29, 869–892 (2022). https://doi.org/10.1007/s10934-022-01219-z
8. *Mihan H. McKenna, Sarah L. McComas, R. Danielle Whitlow, Henry Diaz-Alvarez, Anna M. Jordan, R. Daniel Costley, Christopher P. Simpson*. Remote structural infrasound: Case studies of real-time infrastructure system monitoring. // Journal of Infrastructure Systems. 27(3), 2021, 04021021. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000623
9. *I Sihar* (2022). Numerical modelling of transient low-frequency sound propagation and vibration in buildings. [Phd Thesis 1 (Research TU/e / Graduation TU/e), Built Environment]. Eindhoven University of Technology. 247 p.
10. *V. Glyva, O. Zaporozhets, L. Levchenko, N. Burdeina, V. Nazarenko.* Methodological Foundations Protective Structures Development For Shielding Electromagnetic And Acoustic Fields. // Strength of Materials and Theory of Structures 110, 2023, PP. 245-255.https://doi.org/10.32347/2410-2547.2023.110.245-255
11. *E. Taban, A. Tajpoor, M. Faridan et al.* Acoustic Absorption Characterization and Prediction of Natural Coir Fibers. // Acoust Aust 47, 67–77 (2019). https://doi.org/10.1007/s40857-019-00151-8

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ТЕОРЕТИЧНІ ТА ЕКСПЕРИМЕНТАЛЬНІ ЗАСАДИ ПРОЄКТУВАННЯ ЗВУКОІЗОЛЯЦІЇ БУДІВЕЛЬ І СПОРУД

Розроблено засади проєктування звукоізоляції будівель і споруд з використанням матеріалів різних фізичних характеристик. Показано можливості спрощення розрахунків звукоізоляції для малих значень фазових швидкостей згинних хвиль у матеріалі поверхні. Показано, що така умова відповідає малим значенням частот звуку порівняно з критичною частотою поверхні. Визначено межі прийнятної похибки розрахунків з урахуванням переважності резонансного та інерційного поглинання звуку. Ці межі приблизно відповідають частотам звуку $f < 0,5f_c$, $0,5f_c < f < 1,2f_c$ та $f > 1,2f_c$, f_c – критична частота поверхні обраних масогабаритних параметрів. Отримано математичні функції для розрахунку звукоізоляції поверхонь з м'яких матеріалів. Визначено значення функцій відгуку поверхонь різних розмірів. Показано, що для частот, вищих за 300–400 Гц функція відгуку наближається до одиниці і її можна не враховувати. Такий висновок підтверджується експериментальними даними, які мають прийнятний збіг з розрахунками. Це значно спрощує практичну діяльність з проєктування звукоізоляційних конструкцій. Визначено засади проєктування двошарової структури для підвищення звукоізоляції. Встановлено, що звукоізоляція підвищується зі збільшенням зазору між поверхнями. Але за відстаней, більших за $7–8\cdot10^{-2}$ м підвищення звукоізоляції не відбувається, тому збільшення габаритних розмірів звукоізоляційних конструкцій не є недоцільним.

Ключові слова: звукоізоляція, пружні модулі, критична частота, функція відгуку.

Burdeina N.B., Glyva V.A., Levchenko L.O., Biruk Y.I., Nesterenko O.V.

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The principles of designing sound insulation of buildings and structures using materials of different physical characteristics are developed. The possibilities of simplifying sound insulation calculations for small values of the phase velocities of bending waves in the surface material are shown. It is shown that such a condition corresponds to small values of sound frequencies compared to the critical frequency of the surface. The limits of the acceptable error of calculations are determined, taking into account mainly resonant and inertial sound absorption. These limits roughly correspond to the sound frequencies $f < 0{,}5f_c$, $0{,}5f_c < f < 1{,}2f_c$ and $f > 1{,}2f_c$, f_c being the critical surface frequency of these mass and dimensional parameters. The mathematical functions for calculating the sound insulation of surfaces made of soft materials are obtained. The values of the response functions of surfaces of different sizes are determined. It is shown that for frequencies above 300–400 Hz, the response function approaches unity and can be ignored. This conclusion is confirmed by experimental data, which have an acceptable agreement with the calculations. This greatly simplifies the practical design of soundproof structures. The principles of designing a two-layer structure to improve sound insulation are determined. It was found that sound insulation increases with an increase in the gap between the surfaces. However, at distances greater than $7\text{-}8\cdot10^{-2}$ m, there is no increase in sound insulation, so an increase in the overall dimensions of soundproof structures is impractical.

Keywords: sound insulation, elastic modules, critical frequency, response function.

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Розроблено засади проєктування звукоізоляції будівель і споруд з використанням матеріалів різних фізичних характеристик. Визначено засади проєктування двошарової структури для підвищення звукоізоляції. Встановлені оптимальні значення зазорів між двома поверхнями.

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The principles of designing sound insulation of buildings and structures using materials of different physical characteristics are developed. The principles of designing a two-layer structure to improve sound insulation are determined. The optimal values of the gaps between two surfaces are determined.

Fig. 1. Refs. 11.

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