

OPTIMAL SELECTION OF STYROFOAM AS A FILLING MATERIAL IN THE CONSTRUCTION OF VERTICAL VIBRATION ISOLATION BARRIERS FOR BUILDING FOUNDATIONS

CHAVDAR KOLEV

*Higher School of Transport “Todor Kableshkov”,
158 Geo Milev St, Sofia 1574, Bulgaria,
e-mail: ch.kolev@vtu.bg*

Abstract. A large field experiment was conducted in 2019, which proved the high efficiency of vertical vibration isolation for the foundations of buildings and their quantitative parameters in a particular situation. A second experiment was then carried out, the results of which are presented in this report. The parameters and type of vibration insulation materials suitable for permanent vertical vibration insulation of buildings have been experimentally optimized. Insulation materials were pre-selected according to their catalog parameters. With the new project, we aim to achieve optimization of the appropriate materials depending on their characteristics for energy extinguishing, so that the end result of the vibration isolation system has the highest technical-economic effect. Experiments were conducted with six different types of styrofoam. It turns out that the thickness of the material does not matter as much as its density and composition. Styrofoam, which contains graphite, is better at dampening vibrations than white styrofoam. Styrofoam, which better insulates heat, also insulates vibration better. Extensive analyzes have been made of the influence of the different mechanical characteristics of the insulating material on its anti-vibration damping ability.

Keywords: anti-vibration, styrofoam, damping, trench, efficiency, insulation.

1. PURPOSE OF THE STUDY

The purpose of this study is the experimental determination of the parameters and the type of vibration insulation materials suitable for permanent vertical vibration insulation of buildings. The performed nature experiment in 2019 [1] proved the high efficiency of the vertical vibration isolations and

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their quantitative parameters in a certain specific situation. Then the insulation material was pre-selected according to catalog parameters. Styrofoam was found to exhibit better vibration isolation qualities, even than air. With the new project, we aim to select the most suitable insulation material according to the results of the experiment. So, we want to achieve the highest technical-economic effect. In particular, different types of styrofoam were studied here and the optimal solution to the problem was sought.

The insulation is suitable for both existing and new buildings and facilities. Our research within the previous project from 2019 shows that in Bulgaria there is neither theoretical nor practical experience on this topic, and this type of research is very small in the world.

2. THE MAIN TASKS PERFORMED IN THIS STUDY

1. A suitable range of polystyrene foam insulation materials and its derivatives available on our market was selected and delivered.
2. The necessary technical information on the characteristics of the delivered test materials has been collected.
3. With the help of special measuring equipment, we performed a long series of measurements of the transmitted oscillations through the five samples of the insulating material, as well as through a wooden plate, which serves as a contrasting criterion.
4. Finally, all experimental results were systematized and analyzed in order to find the correlations between them in different logical profiles regarding vibration isolation, such as e.g.:
 - the density of the materials;
 - the chemical and structural composition of the materials.
5. From the analysis of the results, we made a conclusion about the influence of the thickness of the insulation screens of synthetic materials under certain vibration effects.
6. Other useful results for theory and practice are the established values for the damping coefficients of the applied materials.
7. The results complement and expand the results of the previous project [1] from 2019, where the necessary depth of the vibration isolation barrier, the diffraction parameters and a number of other indicators were proved experimentally.

3. THEORETICAL PREREQUISITES FOR THE STUDY AND STATE OF THE ART

The accepted theoretical basis of the research is the Theory of Flat Mechanical Wave, resp. the Theory of signals and heat radiation [2].

We obtained data on the realized accelerations in the test specimens during the set oscillations from the source.

The diagrams for them represent the so-called Effective value of the signal (X_{RMS}), which is the root mean square value of the signals in the spectrum for a given final time interval:

$$X_{RMS} = \sqrt{\frac{1}{n} (x_1^2 + x_2^2 + \dots + x_n^2)} \quad (1)$$

where: $x_1, x_1, \dots, x_n$ are the signals values and n is their number.

Secondly, we have data on the spectral density of the signal as a function of frequency.

Definition: The spectral density of a signal represents the amount of energy in a given final frequency range $[f_0; f + \Delta f]$, which is contained in a unit volume of the body placed between perfectly reflective walls [3].

In the experiment, the signal represents the spectrum of waves caused by the oscillations of the shock-rotating drill on the styrofoam specimen, pressed on both sides by thin steel plates, considered to be perfectly reflective walls. The time for the signal to pass through the “sandwich” of the sample from one plate to the other is taken as a finite time interval $[t; t + \Delta t]$, the frequency of the input signal is f_0 and that of the output signal is $f + \Delta f = f'$.

The mathematical expression for the spectral bulk density ρ_v as a function of the total energy E is the following:

$$\rho_v = E \cdot f / m, \quad [\text{m}^2/\text{s}^3], \quad (2)$$

f – is the signal frequency $[\frac{1}{\text{s}}$ or Hz], m – is the mass of the material $[\text{kg}]$, E – represents the total energy, i.e. the sum of the kinetic E_k and the potential energy E_p of the plane wave.

For plane waves, it is assumed that $E_k = E_p$ and therefore:

$$E = 2 \cdot E_k = 2 * mV^2/2 = mV^2. \quad (3)$$

Spectral bulk density can also be defined as the ratio of the square of the acceleration to the frequency

$$\rho_v = a^2 / f \quad [\text{m}^2/\text{s}^3], \quad (4)$$

as well as the product of the square of the speed of the frequency

$$\rho_v = f/V^2 \text{ [m}^2/\text{s}^3\text{]}. \quad (5)$$

It is seen that the spectral bulk density of the ρ_v signal does not depend on the nature of the body, but only on its mass m and frequency. The mass of a body is a function of its bulk density ρ , so it can be considered that the spectral bulk density of the signal ρ_v is also a function of the mechanical density ρ of the body [3].

There is a concentration of energy E and the spectral density of the signal ρ_v when the frequencies are resonant.

The change in signal frequency when crossing the barrier was considered in accordance with the Doppler effect [3]. When the wave (signal) passes through the barrier of styrofoam, it enters with a certain speed V_0 and frequency f_0 , but leaves with changed values of these two quantities - V' and f' . In such situations, the Doppler effect occurs:

$$V' = \frac{(f' - f_0) \cdot V_0}{(f' + f_0)} \text{ [m/s]}, \quad (6)$$

whence it follows that

$$\frac{V'}{V_0} = \frac{(f' - f_0)}{(f' + f_0)}. \quad (7)$$

The recorded input and output spectra are different precisely because of the Doppler effect. If a spectral bulk density $\rho_{v0} = f(E_{i0})$ is obtained at the input of the system (at the application point of the waveform – the drill) for frequency f_0 , then at the output for the same frequency of the spectrum another value of the volumetric spectral density $\rho'_v = f(E'_i)$. The final value of the spectral bulk density ρ'_v is lower than the initial ρ_{v0} because the initial wave energy is dissipated (absorbed) in the styrofoam barrier. The amorphous structure of styrofoam and its very low volumetric weight contribute to the dissipation in this sense. In the case of a wooden rigid fence, the mechanical density, resp. the mass is much larger, inertial force accumulates in it from forced oscillations, there is no absorption and an amplifying effect (acceleration) is obtained. Thus, in the case of a wooden barrier, the final value of the spectral bulk density ρ'_v is higher than the initial ρ_{v0} .

The ability of prototypes to absorb and emit energy is considered within the context of Kirchhoff's Law [4]. The quantitative relationship between the radiant $K_{v,T}^*$ and the absorbing $A_{v,T}^*$ capacity of a body is proportional to the spectral bulk density and is expressed by Kirchhoff's Law which mathematical

expression is as follows:

$$\frac{K_{v,T}^*}{A_{v,T}^*} = \frac{c}{8\pi} \rho_v, \quad (8)$$

where c – the speed of light, ρ_v – the spectral bulk density.

Since ρ_v does not depend on the nature of the material, the ratio $\frac{K_{v,T}^*}{A_{v,T}^*}$ also does not depend on it and has the same value for all bodies at a given frequency and temperature. This ratio is a universal function $f(n, t)$ of frequency n and temperature t , called the Kirchhoff function.

It is known that the absolutely black body only absorbs energy without emitting, and for him Kirchhoff's Law [4] takes the form:

$$K_{v,T}^* = \frac{c}{8\pi} \rho_v. \quad (9)$$

It follows from this expression that Kirchhoff's universal function is in fact the radiant power of an absolutely black body.

The results of all measurements were processed and presented in Fourier series in spectral form.

In preparing and conducting the experiment, the conclusions were recorded in [2, 5, 6–8].

4. EXPERIMENTAL RESEARCH

A test of seven samples was performed, for which we established their energy-extinguishing effect under the influence of external concentrated oscillations. Six specimens are made of styrofoam, and the seventh specimen is a wooden beech tile. The wooden tile was tested to verify the values of the result values of the other six samples. Styrofoam is expected to absorb a lot of energy in advance, respectively to reduce the impact of oscillations, and wood with its high density and stiffness back, to transmit and strengthen them.

The experimental setup is as follows:

- The sample (styrofoam) is placed between two steel plates with a thickness of 3 mm and the “sandwich” is placed vertically (See Fig.4).
- One sensor for input and output signals is attached to the surfaces of the steel plates (See Figs. 2 and 3).
- In front of the sample, a hand drill is stationary and tightened with a percussion-rotating mechanism, but with the drill bit cut off (See Fig. 1).
- The sensors are connected to a power supply and a computer with an installed program for recording signals (See Fig. 2).

- For each sample, shock-rotating effects are given by letting the drill hit the steel plate in front of it. The drill is activated by a manual button and the created oscillations do not have constant parameters (See Fig. 1).



Fig. 1. View from the input signal and the impact drill



Fig. 2. View from the output signal and the recording computer

Measurements were made on the three axes: X – along the axis of the drill, perpendicular to the plane of the sample; Y – tangential to the plane of the sample in the horizontal plane formed by the X axis; Z – vertically down. The application point of the oscillation source (drill) is accepted as the beginning of the coordinate system (Fig. 5). In the text of this report the conducted experiments are numbered respectively: Test 1, Test 2, ..., Test 7. The first 6 experiments with the varieties of styrofoam, and the last seventh sample is

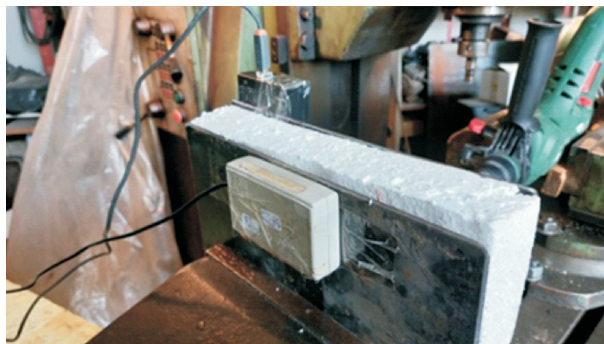


Fig. 3. Detail of the output sensor



Fig. 4. Vertical profile of the installation

from the wooden tile. The experiment with the sixth sample (Test 6) was not entirely successful and reliable results and records from the measurement on the input sensor could not be achieved. Therefore, this experience is not analyzed in the Project. The data and names of the test specimens are presented in survey tables 8, 9, 10 and 11. The presented photos from Figs. 1–4 also correspond to the setup of the sample from Test 2.

The results of the individual experiments are presented in Tables 1, 2, 3, 4 up to 11 and 12.

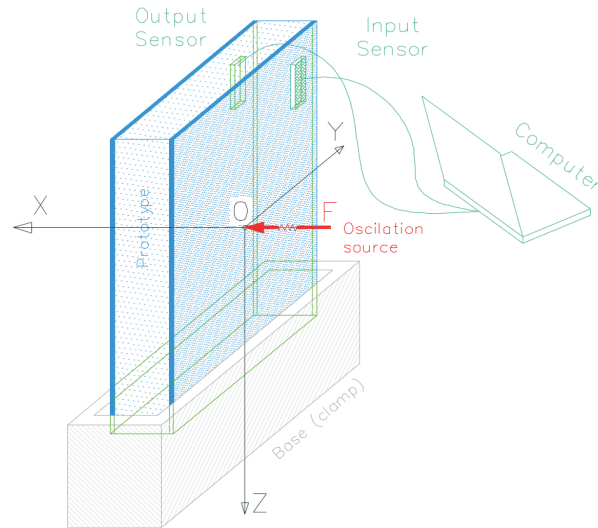


Fig. 5. Scheme of the experiment with the coordinate system

4.1. Test 1

Prototype: Styrofoam, white, 5 cm thick.

Table 1. Effective signal value

No	Charac- teristics	Time t[s]	Acceleration		Damper effect		
			a_0	a'	a'/a_0	$\left(1 - \frac{a'}{a_0}\right) * 100$ [%]	Average values
1	$Max\ a_0$	4.91	0.1157g	0.0327	0.283	71.7%	74.15%
2	$Min\ a_0$	28.45	0.0543g	0.0127	0.234	76.6%	
3	$Max\ a'$	20.27	0.0957g	0.0523	0.546	45.4%	61%
4	$Min\ a'$	28.95	0.0543g	0.0127	0.234	76.6%	
						$S = 270.3\%$	67.58%

The source of the oscillations creates a spectrum of signals that are picked up by the sensors and recorded on the computer. These signals change their frequency when passing through the styrofoam, and therefore the values of the frequencies at the input f_0 and at the output f' are recorded. For the purposes of our analysis, the extreme values of these quantities from the entire signal spectrum are of interest. Therefore, the values $\max f_0$ and $\min f_0$, $\max f'$ and $\min f'$, $\max a_0$ and $\min a_0$, $\max a'$ and $\min a'$ are recorded in the tables. Therefore, in the tables of all the experiments shown here, only the extreme

values of the frequencies and accelerations along the X-axis are presented and analyzed.

On Table 2, as well as the following tables below: 4, 6, 8, 10 and 12, the values of the difference $f' - f_0$ and of the sum $f' + f_0$ are also calculated for the input and output signal maxima. These maxima are marked in bold in the tables. Similarly, the ratio $\frac{\rho'_v}{\rho_{v0}}$ is calculated in these tables. The maximum of ρ'_v is written in the numerator and the maximum of ρ_{v0} is written in the denominator.

Table 2. Spectral density of the signal

No	Charac- teristics	Input signal		Output signal		$f' - f_0$	$f' + f_0$	$\frac{f' - f_0}{f' + f_0}$	$\frac{\rho'_v}{\rho_{v0}}$
		Fre- quency f_0 [Hz]	Spectrum density ρ_{v0} [m ² /s ³]	Fre- quency f' [Hz]	Spectrum density ρ'_v [m ² /s ³]				
1	<i>Max. Input</i>	20	0.025	6	0.003	-5	35	-0.143	2.132
2	<i>Max. Output</i>	20	0.025	15	0.0533				

4.2. Test 2

Prototype: Styrofoam, white, 10 cm thick.

Table 3. Effective signal value

No	Charac- teristics	Time t[s]	Acceleration		Damper effect		
			a_0	a'	a'/a_0	$\left(1 - \frac{a'}{a_0}\right) * 100$ [%]	Average values
1	<i>Max a_0</i>	21.9	0.0941	0.0341	0.362	63.8%	59.8%
2	<i>Min a_0</i>	39.91	0.0453	0.0200	0.442	55.8%	
3	<i>Max a'</i>	32.10	0.0788	0.0351	0.4434	55.5%	61%
4	<i>Min a'</i>	24.50	0.0535	0.0178	0.333	66.7%	
						S = 241.8%	60.4%

Table 4. Spectral density of the signal

No	Charac- teristics	Input signal		Output signal		$f' - f_0$	$f' + f_0$	$\frac{f' - f_0}{f' + f_0}$	$\frac{\rho'_v}{\rho_{v0}}$
		Fre- quency f_0 [Hz]	Spectrum density ρ_{v0} [m ² /s ³]	Fre- quency f' [Hz]	Spectrum density ρ'_v [m ² /s ³]				
1	<i>Max. Input</i>	17143	0.01376	17.143	0.0252	-9.643	24.643	-0.391	0.305
2	<i>Max. Output</i>	7.5	0.004	7.5	0.0042				

4.3. Test 3

Prototype: Styrofoam, white with charcoal impurities, 5 cm thick.

Table 5. Effective signal value

No	Charac- teristics	Time t[s]	Acceleration		Damper effect		
			a_0	a'	a'/a_0	$\left(1 - \frac{a'}{a_0}\right) * 100$ [%]	Average values
1	<i>Max a_0</i>	48.27	0.279	0.053	0.19	81%	53.05%
2	<i>Min a_0</i>	20.73	0.0895	0.067	0.749	25.1%	
3	<i>Max a'</i>	4195	0.197	0.07	0.355	64.5%	63.65%
4	<i>Min a'</i>	5	0.094	0.034	0.372	62.8%	
						S = 233.4%	58.35%

Table 6. Spectral density of the signal

No	Charac- teristics	Input signal		Output signal		$f' - f_0$	$f' + f_0$	$\frac{f' - f_0}{f' + f_0}$	$\frac{\rho'_v}{\rho_{v0}}$
		Fre- quency f_0 [Hz]	Spectrum density ρ_{v0} [m ² /s ³]	Fre- quency f' [Hz]	Spectrum density ρ'_v [m ² /s ³]				
1	<i>Max. Input</i>	18.57	0.02342	18.57	0.00195	5.32	42.46	0.125	0.254
2	<i>Max. Output</i>	23.89	0.003	23.89	0.00595				

4.4. Test 4

Prototype: Styrofoam, black and white with graphite impurities, 8 cm thick.

Table 7. Effective signal value

No	Charac- teristics	Time t[s]	Acceleration		Damper effect		
			a_0	a'	a'/a_0	$\left(1 - \frac{a'}{a_0}\right) * 100$ [%]	Average values
1	<i>Max</i> a_0	11	0.054	0.0475	0.88	12%	-24%
2	<i>Min</i> a_0	20	0.025	0.04	1.60	-60%	
3	<i>Max</i> a'	14	0.042	0.051	1.21	-21%	-4.5%
4	<i>Min</i> a'	30.2	0.034	0.030	0.88	12%	
						S = -57%	-14.25%

Table 8. Spectral density of the signal

No	Charac- teristics	Input signal		Output signal		$f' - f_0$	$f' + f_0$	$\frac{f' - f_0}{f' + f_0}$	$\frac{\rho'_v}{\rho_{v0}}$
		Fre- quency f_0 [Hz]	Spectrum density ρ_{v0} [m ² /s ³]	Fre- quency f' [Hz]	Spectrum density ρ'_v [m ² /s ³]				
1	<i>Max.</i> <i>Input</i>	18.5	0.011	18.5	0.022	-11	26	-0.423	4.91
2	<i>Max.</i> <i>Output</i>	7.5	0.003	7.5	0.054				

4.5. Test 5

Prototype: Styrofoam, gray, with graphite, with structural holes, 11.5 cm thick.

Table 9. Effective signal value

No	Charac- teristics	Time t[s]	Acceleration		Damper effect		
			a_0	a'	a'/a_0	$\left(1 - \frac{a'}{a_0}\right) * 100$ [%]	Average values
1	<i>Max</i> a_0	12.3	0.383	0.057	0.149	85.1%	79.85%
2	<i>Min</i> a_0	22	0.295	0.075	0.254	74.6%	
3	<i>Max</i> a'	4.5	0.35	0.12	0.343	65.7%	75.55%
4	<i>Min</i> a'	30	0.35	0.051	0.146	85.4%	
						S = 310.8%	77.7%

Table 10. Spectral density of the signal

No	Charac- teristics	Input signal		Output signal		$f' - f_0$	$f' + f_0$	$\frac{f' - f_0}{f' + f_0}$	$\frac{\rho'_v}{\rho_{v0}}$
		Fre- quency f_0 [Hz]	Spectrum density ρ_{v0} [m ² /s ³]	Fre- quency f' [Hz]	Spectrum density ρ'_v [m ² /s ³]				
1	<i>Max. Input</i>	18.5	0.11	18.5	0.0043	1.5	38.5	0.039	0.227
2	<i>Max. Output</i>	20	0.04	20	0.025				

4.6. Test 7

Prototype: Wooden tile, beech, 3 cm thick.

Table 11. Effective signal value

No	Charac- teristics	Time t[s]	Acceleration		Damper effect		
			a_0	a'	a'/a_0	$\left(1 - \frac{a'}{a_0}\right) * 100$ [%]	Average values
1	<i>Max a_0</i>	39	0.033	0.038	1.15	-15%	-100.5%
2	<i>Min a_0</i>	9	0.0105	0.030	2.86	-186%	
3	<i>Max a'</i>	4	0.020	0.045	2.25	-125%	-92.85%
4	<i>Min a'</i>	17.5	0.014	0.0225	1.607	-60.7%	
						S = -386.7%	-96.67%

Table 12. Spectral density of the signal

No	Charac- teristics	Input signal		Output signal		$f' - f_0$	$f' + f_0$	$\frac{f' - f_0}{f' + f_0}$	$\frac{\rho'_v}{\rho_{v0}}$
		Fre- quency f_0 [Hz]	Spectrum density ρ_{v0} [m ² /s ³]	Fre- quency f' [Hz]	Spectrum density ρ'_v [m ² /s ³]				
1	<i>Max. Input</i>	3.4	0.00675	3.4	0.00275	+4.6	11.4	+0.404	1.378
2	<i>Max. Output</i>	8	0.00085	8	0.0093				

The results for the spectral density values from the six relevant experiments are compared in Table 13.

Table 13. Summary comparative table of spectral density values

No	Test No	Max ρ_v	Fre- quency $\rho_{v \max}$ [Hz]	Material	Doppler effect V'/V_0	$\frac{\rho'_v}{\rho_{v0}}$	Damper effect
1	1	Input	0.025	20	-0.143	2.132	67.58%
2		Output	0.00533	15			
3	2	Input	0.01376	17.143	-0.391	0.305	60.45%
4		Output	0.0042	7.5			
5	3	Input	0.02342	18.57	0.125	0.254	58.35 %
6		Output	0.00595	23.89			
7	4	Input	0.011	18.5	-0.423	4.91	-14.25%
8		Output	0.0054	7.5			
9	5	Input	0.11	18.5	0.039	0.227	77.7%
10		Output	0.025	20			
11	7	Input	0.00675	3.4	0.404	1.378	-96.67%
12		Output	0.0093	8			

The comparison of the results for the measured extreme effective values of the accelerations are shown in Table 14.

Table 14. Summary comparison table for the obtained accelerations

Test No	Signal	$a_{\max}$	$a_{\min}$	Δ_a	Remarks
1 5 cm	Input	0.120g	0.055g	0.065g	Δ_a shows 60% narrowing (1.66 times) of the acceleration range.
	Output	0.052g	0.013g	0.039g	
	Δ_a	0.068g	0.042g	0.026g	
2 10 cm	Input	0.138g	0.036g	0.102g	Δ_a is double compared to Test No 1.
	Output	0.070g	0.056g	0.014g	Δ_a is almost 3 times narrower than No 1.
	Δ_a	0.068g	0.020g	0.088g	The sample is 3.4 times less homogeneous than in Test No 1.
3 5 cm	Input	0.140g	0.070g	0.070g	Δ_a is almost identical to Test 1; Their thickness is the same.
	Output	0.066g	0.033g	0.033g	Δ_a is almost identical to Test No 1.
	Δ_a	0.074g	0.037g	0.037g	Δ_a is of approximately the same order with Test 1 (The sample is 1.4 times less homogeneous than that of Test 1)
4 Black- white, 8 cm	Input	0.054g	0.025g	0.029g	Δ_a is more than 2 times less than in Test 1
	Output	0.051g	0.030g	0.021g	Approximately 2 times less than No 1
	Δ_a	0.003g	-0.005g	-0.002g	Very low value/higher homogeneous
5 Gray, 11.5 cm	Input	0.383g	0.295g	0.088g	3.4 times
	Output	0.350g	0.051g	0.299g	29.4%
	Δ_a	0.033g	0.244g	-0.211g	Approx. 70.6% damping
7 tree, 3 cm	Input	0.033g	0.0105g	0.0225g	1 : 1
	Output	0.045g	0.0225g	0.0225g	
	Δ_a	-0.012g	-0.0120g	-	Homogeneous

5. DISCUSSIONS

5.1. Assessments from the comparison of the results

The damping effect of white styrofoam is higher with styrofoam with lower density (Test 1 – Tabl. 1 and 2), which meets our expectations.

The included graphite grains in the structure of styrofoam (Test 3 – Tabl. 5 and 6) increase its stiffness and density, homogenize it, do not reduce its damping effect.

The thickness of the styrofoam in the range from 5 cm to 10 cm does not affect its damping effect (Tests 1 and 2 – Tabl. 1, 2, 3 and 4).

Gray styrofoam (entirely graphite) (Test 5 – Tabl. 9 and 10), which also has structural holes, has a higher energy efficiency of about 15% to 28% compared to white styrofoam (Tests 1 and 2 – Tabl. 1, 2, 3 and 4).

The spectral density of gray all-graphite styrofoam (Test 5 – Tabl. 9 and 10) is about 34% lower than that of white styrofoam (Tests 1 and 2 – Tabl. 1, 2, 3 and 4). This indicator proves the better energy-extinguishing effect.

The reduction of the signal speed V compared to the initial speed V_0 (Doppler effect) in gray styrofoam is about 10 times compared to white (Tabl. 8).

Resonant frequencies and their octaves are almost identical in practice, their approximate value is 18.5 Hz (Tabl. 8).

Styrofoam from Test 1 has the lowest density and the lowest homogeneity. Therefore, it has the widest ranges of accelerations Δa (Table 14).

Styrofoam with graphite impurities (Test 4) is much more homogeneous than white and therefore the range of accelerations is very narrow. This reduces its energy-extinguishing effect (Table 14).

In the case of styrofoam from Test 2, the density is much higher compared to that from Test 1 and therefore the range of accelerations Δa is narrower and the damping effect is lower (by about 12%) (Table 14).

The values of the physical and mechanical characteristics of the tested materials from the five relevant experiments are compared in Table 15. In the last column “Remarks” of the table, the difference between the maximum and minimum values of the corresponding indicators obtained in the five trials is evaluated. A smaller range of values is an indication of higher confidence in the mean.

Table 15. Summary comparative table of physical and mechanical characteristics

No	Indicator	EPS test product					Remarks
		Test 1: Austro- term T 1000	Test 2: Refix 70F	Test 3: Austro- term F	Test 4: Austro- term F+	Test 5: Globus F80 Graphite	
1	Bulk density r	15.2 kg/m ³	14.2 kg/m ³	15 kg/m ³	15 kg/m ³	16.5 kg/m ³	The differences are not big, up to 16%!
2	Compressive strength S_{10}	44 kPa	85 kPa	≥ 80 kPa	≥ 80 kPa	86 kPa	The differences are big, 3 ÷ 95%!
3	Tensile strength S_{mt}	122 kPa	160 kPa	≥ 150 kPa	≥ 150 kPa	170 kPa	The differences are big, 6 ÷ 39%!
4	Bending strength S_b	169 kPa	155 kPa	≥ 170 kPa	≥ 170 kPa	165 kPa	The differences are not big, 3 ÷ 10%!
5	Water absorption for 7 days W_{it7}	2.1 %	1.4 %	≤ 2 %	≤ 2 %	1.8 %	The differences are big, 11 ÷ 50%!
6	Water absorption for 2 days W_{it2}	0.21%	0.085 %	≤ 0.2 %	≤ 0.2 %	0.072 %	The differences are big, 5 ÷ 290%!
7	Remarks	The characteristics of Test 1 are less favorable than those of Test 2.		All characteristics are the same. They are close to those of Test 2.		These features are the best!	

5.2. Assessments from the comparison of the physical and mechanical characteristics

In the state of water saturation (W_{it7}) all materials approach their values, and at low humidity (W_{it2}) the values are different! In water-saturated and dry conditions, the materials from Test 2 and Test 5 are the most suitable!

The higher compressive strength of materials from Test 2 to Test 5 makes them more resistant to earth pressure in the trench.

The combination of the more favorable strength and watertight performance of Test 2 and Test 5 makes them more suitable for isolation of vibrations in the trench compared to other products.

In terms of strength and water-tightness, the materials for Test 3 and Test 4 are slightly better than those for Test 1.

The differences in bulk density values are not large, but the material for Test 2 has a 5% lower density than those for Test 1, Test 3 and Test 4 and gives better damping. The material for Test 5 has the highest density (16% more than Test 2), but the presence of graphite enhances damping and compensates for the effect of higher density.

The differences in compressive strength σ_c are also not large (from 3% to 10%) except for the sample from Test 1. They are a function of the density ρ . However, products with lower compressive strength values create a higher damping effect and relatively less retention of earth pressure in the trench. An exception is gray styrofoam, where again the content of graphite makes it the most effective for damping, despite its higher strength.

The differences in tensile strength are larger (from 6% to 39%) and follow the dependencies on compressive strength. The gray tensile strength from Test 5 has the highest tensile strength, and among the white styrofoam samples with the highest tensile strength is the one from Test 2. The highest values of tensile strength and pressure for the samples from Test 5 and Test 2 make them the most tough, which is why, compared to the other samples, they mainly absorb the higher frequencies of the spectrum. So, they absorb the ground pressure best, but the material for Test 2 is not the best damper, while the graphite in Test 5 helps the material to absorb the most energy.

The aim of the task is to find the optimal combinations between the density, strengths and spectral density of each sample in order to achieve the maximum damping effect at the best resistance against the earth pressure in the trench. Of the analyzes presented so far, the gray styrofoam from Test 5 is the most suitable, followed by the white one from Test 2. On top of all that, the graphite samples absorb less water.

6. CONCLUSIONS

Classification of insulation materials according to the complex assessment of them by indicators and reports is made in Table 16. The table shows a rating of the five materials according to the experimental results shown. It is accepted that the highest score is 5 and it is given when the material has shown the most favorable value for the purposes of vibration isolation, and the lowest score is 1 and is given to the material that has shown the most unfavorable values for vibration isolation during testing of its certain quality. Finally, the differentiated ratings were collected for each material and, according to their sum, the rating for the most suitable Styrofoam to be applied for vibration isolation of building foundations was obtained. The highest amount indicates the most suitable material and vice versa.

Table 16. Selection of optimal damping material

Sample	Test No	Overall assessment	Differentiated assessments according to physical and mechanical characteristics				
			By density	By quality	By water tightness	By spectral density	By reducing acceleration
Globus F80 Graphite	5	24	5	5	4	5	5
Refix 70F	2	17	2	4	5	3	3
Austroterm T 1000	1	16	4	2	2	4	4
Austroterm F	3	13	3	3	3	2	2
Austroterm F+	4	10	3	3	3	–	1

For comparison, the thermal conductivity coefficients of the tested materials are compared (Table 17). Interestingly, this ranking is very similar to the complex assessment of Table 17. Therefore, the thermal conductivity characteristics follow the logic of the energy-extinguishing properties of the material, which was seen from Kirchhoff's Law and the Compton Effect in the theoretical justification of our experiment.

The most suitable material is again the graphite styrofoam from Test 5, followed by the styrofoam for Test 4, which has less graphite. Of the white styrofoam, the most suitable is again the one from Test 2.

Table 17. Comparison of thermal conductivity materials

Test No	Brand	Thermal conductivity coefficient	Thermal resistance at 5 cm thick	Sample thickness	Thermal conductivity rating
		W/m.K	W ² .K/W	cm	
1	Austroterm T1000	0.040		5	5
2	Refix 70F	0.034	1.47/2.94	10	3
3	Austroterm F	≤ 0.038		5	4
4	Austroterm F+	≤ 0.031		8	2
5	Globus F80 Graphite	0.028	1.79/4.29	11.5	1

6.1 Practical application of the results

The obtained results of the project can be directly applied in the design and implementation of vertical vibration protection screens for buildings and facilities disturbed by passing heavy vehicles: heavy trucks, trains, trams, landing and departure aircraft (airports and hangars) and others. In further theoretical and experimental research, these results will be an important step towards finding effective protection of buildings from seismic impacts [9], where there is a direct analogy with vibration loads. In addition, the results of the project will enrich the theory and practice of the most common problem with vibration protection of foundations under machines.

Especially valuable will be the results of the experience of numerous restorations [10] of historical and immovable cultural monuments [1] throughout the civilized world: buildings, bridges, monuments, etc., which are threatened by the effects of vehicles in modern cities.

The lack of practice in our country and in many places around the world with the construction of vertical vibration protection screens is a prerequisite for the rapid entry of the results of experience in the practice and theory of construction.

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