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Simplified procedure for estimating the acoustic performance over time of floating subfloors in terms of impact noise by the induced creep method

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Abstract

Within the context of subfloor systems performance concerning the impact noise, there is a concern with the behavior of these systems over time, since the creep suffered by the resilient materials that compose these systems can affect their acoustic performance. The method for evaluating this behavior is the determination of creep. Other researchers proposed a correlation between the mentioned method and the determination of compressibility method, such that, this last-mentioned method can be considered an induced creep, as well as a method that allows estimating the acoustic performance of these materials after ten years, from the resonant frequency and induced creep results. Based on this method, this work objective was to develop a simplified procedure to estimate the acoustic performance of resilient materials projected for after ten years under compression. Fourteen samples of resilient materials found in the Brazilian market were covered. A correlation was verified between the resonance frequency and the thickness of the material after application of the load of 2 kPa and application and removal of the load of 48 kPa. With this, two equations were proposed that make it possible, for preliminary analysis, eliminate the step of applying the additional load of 48 kPa, which originally requires a large apparatus.

Keywords: deformation; induced creep; over time; dynamic stiffness; impact noise; floating subfloor; resilient materials; resonance frequency; compressibility; impact hammer; housing buildings.

PACS: 43.20.Ye; 43.40.Kd; 43.40.Tm; 43.50.Gf.



1. INTRODUCTION

The most utilized method to attenuate floor impact noise in buildings in Brazil is the floating floor system, in which blankets of resilient materials are placed between the layer of the floor and the slab. Dynamic stiffness is a determining property for the acoustic performance of these materials.

Some research show that resilient materials may suffer creep due to the loads of the floor and accidental loads to which they are subjected [6-7]. This factor may alter the mechanical properties of these materials, including their dynamic stiffness. This occurs because the compression of resilient materials tends to increase their stiffness and consequently decrease their vibration attenuation capacity.

The performance of floating floor systems is a topic of wide dissemination, but more recently the concern with the duration of the performance of these systems has arisen, due to the materials that suffer creep. Thus, some works have been developed searching for methods to evaluate the performance of these materials over time, such as the creep determination method. The estimative method of evaluation by determining the natural creep demands a minimum measuring time of 90 calendar days, based on ISO 20392 [4].

Schiavi et al. [7] proposed an evaluation method by determining compressibility based on DIN EN 12431:2000 apud Schiavi et al. [7], in which certain loads are applied to the material, causing instantaneous deformations. This method allows predicting the natural creep by determining the compressibility and estimating the resonance frequency and dynamic stiffness of the material projected after 10 years according to Equations 1 and 2.

$$f_{r,B} = \frac{1}{\sqrt{d_B/d_F}} f_{r,F} \text{ (Hz)} \quad (1)$$

$$s'_{10} = (f_{r,B} \cdot 2\pi)^2 \cdot m'_t \text{ (MN/m}^3\text{)} \quad (2)$$

Where:

$f_{r,F}$ is the resonance frequency of the sample after 2 kPa of stress is applied [Hz];

d_F is the thickness of the sample after 2 min under stress application of 2 kPa [mm];

d_B is the thickness of the sample after 2 min under application of additional stress of 48 kPa and 2 to 5 min of stress removal [mm];

m'_t is the apparent mass per unit area during the test [kg/m²].

Thus they verified that the proposed method produces results sufficiently approximate, concerning the natural creep method, to make reliable estimates.

This paper proposes the elaboration of a procedure based on Schiavi et al. [7], for estimating the change in thicknesses caused by material creep predicted to occur after 10 years, simplifying the step of measuring the thicknesses during the compressibility test according to ISO 29770 [5], with estimates that allow eliminating the step of applying the 48 kPa load, in order to facilitate the estimates for preliminary analysis.

In this paper, the method for determining compressibility will be called induced creep.

2. METHOD

The experimental investigation was performed by submitting specimens of resilient materials to the test for determination of induced creep according to ISO 29770 [5] and the tests for measurement of resonance frequencies according to ISO 9052-1 [2], in the Laboratory of Environmental Comfort, Energy Efficiency and Sustainability (LCAP) and in the Laboratory of Technology and Performance of Building Systems (LTDC) of the Institute for Technological Research of the State of São Paulo (IPT), Brazil. With the results obtained, regression analyses were performed in order to verify the relation between these measured factors. The method is explained in more detail in the following subsections.

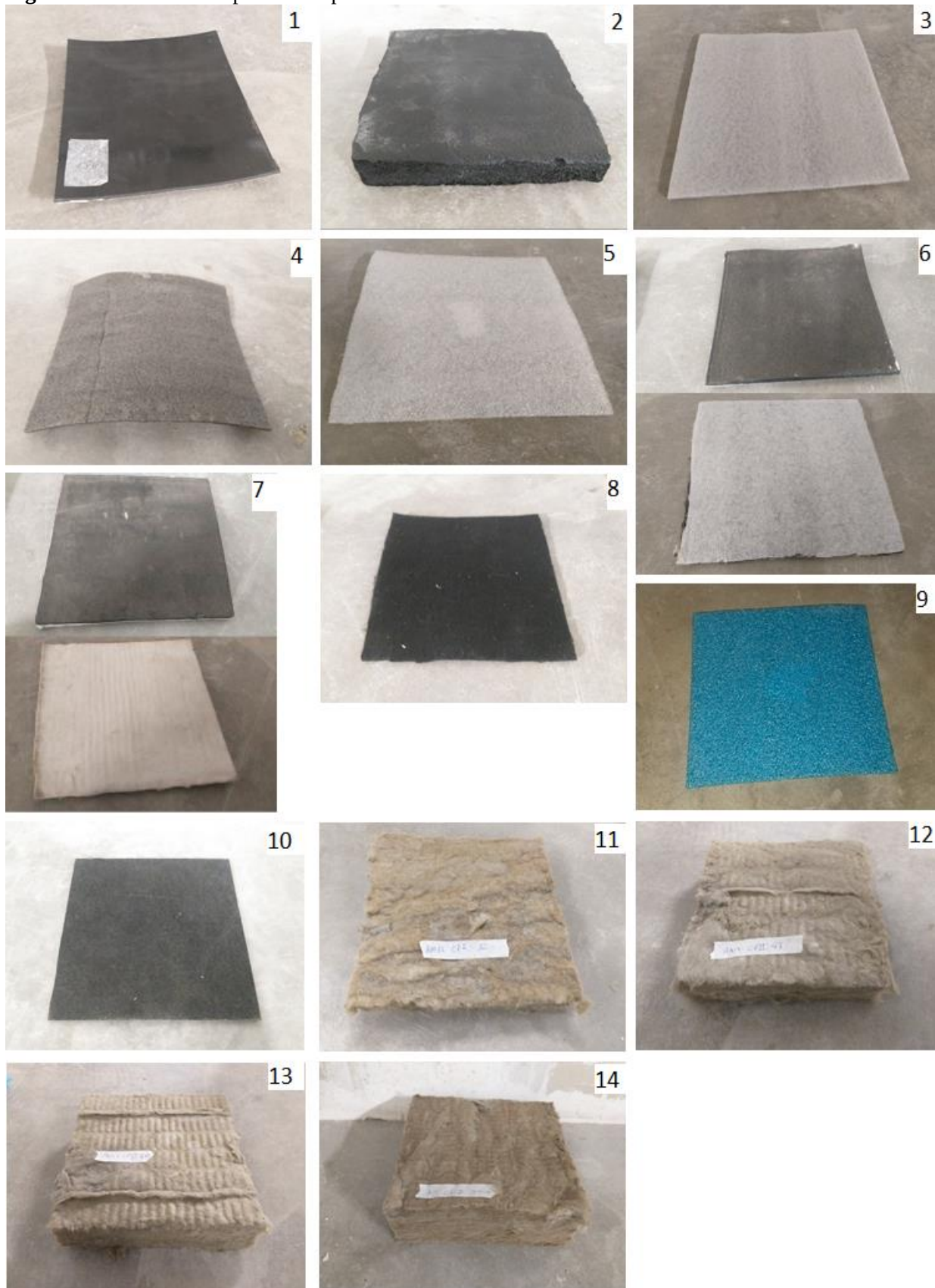
2.1 Materials

Fourteen products available in the national market were chosen, which were donated by suppliers/manufacturers. The samples taken from the products were submitted to an oven for 24 hours at 50 °C and then the dimensions,

masses and calculation of the specific masses of the materials were determined. These data, as well as information about whether the material has open or closed cells, are presented in Table 1. In Figure 1 are presented photographs of the products in the order shown in Table 1.

Table 1 - Description of products used in the tests.

Sample Number	Description	Thickness (mm)	Cells	Specific mass (kg/m ³)
1	EVA foam	5.1	Closed	372.5
2	Nitrile rubber foam	33.0	Closed	44.5
3	EPE (in gray color)	4.9	Closed	340.8
4	EPE (in black color)	4.6	Closed	339.1
5	EPE (in white color)	5.0	Closed	206.0
6	Double Layer Product: asphaltic blanket / EPE	5.3	Closed	1240.7
		3.2	Closed	23.6
7	Double Layer Product: asphaltic blanket / PET wool blanket	5.2	Closed	1252.6
		3.4	Open	13.4
8	PET wool blanket	6.1	Open	104.9
9	EPE (in blue color)	5.2	Closed	265.4
10	Rigid PET wool board	5.1	Open	300.8
11	Rock wool panel (nominal density 32)	48.0	Open	35.0
12	Rock wool panel (nominal density 48)	52.0	Open	47.9
13	Rock wool panel (nominal density 80)	59.0	Open	79.8
14	Rock wool panel (nominal density 144)	64.0	Open	141.6

**Figure 1** – Photos of samples of the products used.

2.2 Tools and Software

Table 2 presents data on the main tools and software used to perform the measurements, their respective functions for this work, and the

reference letter of each piece of equipment, adopted to indicate the equipment used in each step of the method.

Table 2: Ferramentas e softwares utilizados.

Letter	Description	Model	Function
“a”	Impact Hammer with plastic tip	Type 8206 Brüel & Kjær	Excite the system according to the standard ISO 7626-5 [1]
“b”	Triaxial accelerometer with measurement capability of 1-11k Hz (x), 1-9k Hz (y), 1-18k Hz (z)	Triaxial DeltaTron Accelerometer Type 4504 A – Brüel & Kjær	Coupled to the load plate, measure the acceleration caused by the excitation and transmit it as an electrical signal to the data acquirer
“c”	Data acquirer	BZ-7848-A LAN-XI NOTAR – Brüel & Kjær	Read the electrical signals and report them to the analyzer software
“d”	Data analyzer software	PULSE LabShop v. 17.1.1 – Brüel & Kjær	Analyze the reported signals by relating them to each other and translate them into graphics
“e”	Analogical motorized hydraulic press with minimum resolution of 200 g and load limit of 2500 kg	Tinus-Olsen Testing Machine	Applying stresses to materials
“f”	Digital dial gauges (4 units) with a resolution of 0.01 mm and a capacity of 25.4 mm attached to magnetic bases	ID-U1025 Mitutoyo Corp.	Measure the displacement of the hydraulic press load plate during material stress applications
“g”	Digital caliper with 150 mm capacity and 0.01 mm resolution	Mitutoyo ABSOLUTE digimatic	Measure the displacement of the load plate of the hydraulic press during stress applications on materials with displacements above 25 mm.
“h”	Digital depth gauge with 150 mm capacity and 0.01 mm resolution	Mitutoyo ABSOLUTE digimatic - 571-201-30	Measure the displacement of the load plate of the hydraulic press during stress applications on materials with displacements above 25 mm.
“i”	Steel plate with a thickness of 25.4 mm and a mass of 7.8 kg	N/A	Excitation and response vibration transmission bridge for resonance frequency measurements.



2.3 Resonance frequency measurements ($f_{r,F}$)

Measurements of the resonance frequencies $f_{r,F}$ were performed according to ISO 9052-1 [2] by the method of excitation by pulse signals using the impact hammer "a" and the triaxial accelerometer "b", both connected to the data acquirer "c". The concrete floor of the laboratory was used as a base.

As for the software "d", it was configured to average five consecutive impactions, correlate the excitation with the response received in acceleration by calculating the FFT (Fast Fourier Transform), converting this information into amplitude (dB) x frequency (Hz) in a frequency range of interest between 0 and 400 Hz. From the spectrum generated after the measurement it is possible to observe in the peak amplitude the resonance frequency.

The software was also configured to calculate the coherence function of the averages of the measurements to validate them.

In this step some requirements of the ISO 9052-1 standard [2] were not met, namely: use of petroleum jelly on the sides of the materials with closed cells, because no differences were noticed in the results with and without the application of petroleum jelly; the application of a layer of gypsum between the load plate and the resilient materials, because the gypsum has the function of regularizing the surface of materials with raised faces, which is not the case of the samples used in this work.

2.4 Measurement of sample deformations

The specimens were conditioned in a climate controlled room at an average air temperature of 25 °C and 68% relative humidity for 6 hours or more based on ISO 29770 [5].

They were submitted to the induced creep test using the hydraulic press "e".

The press had a load and base plate with sides measuring 200 mm x 200 mm. The four dial indicators "f" were placed on the load plate, one on each corner. In the case of materials with deformations greater than 25.4 mm that would

exceed the capacity of the dial gauges, the calipers "g" and "h" were used on two diagonal corners of the load plate "i".

Measurements of the thicknesses of the specimens were taken after 2 min under stress application of 250 Pa (d_L), after 2 min under application of 2 kPa stress (d_F), after 2 min under application of additional 48 kPa stress, and 2 to 5 min of the removal of this additional stress (d_B) according to ISO 29770 [5].

2.5 Regression analysis

From the results of the resonance frequency measurements $f_{r,F}$ and the thickness measurements d_F and d_B , regression analyses were performed using Excel, with d_B as the dependent variable and $f_{r,F}$ and d_F as independent variables, to obtain equations that make it possible to estimate the d_B thickness.

3. Results and discussion

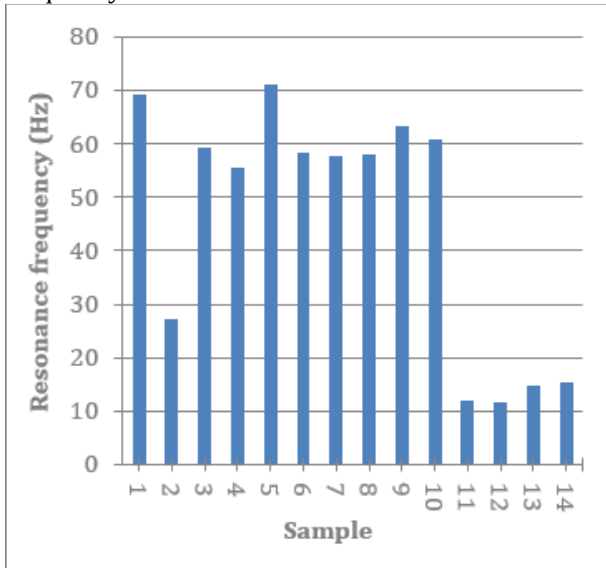
This section presents the results of the resonance frequency measurements, the results of the deformation measurements, the equation estimates obtained from the regression analysis, and the results and discussion of the estimates obtained from the proposed equations.

3.1 Resonance frequency measurements $f_{r,F}$

The average results of the obtained resonance frequency measurements $f_{r,F}$ are presented in Table 3 and graphically in Figure 2.

The coherences of the measurements were also checked, being between 0.9 and 1 (the coherence results of each measurement were not presented individually in this paper). Therefore, the results are considered valid.

Figure 2: Graph with the results of the resonance frequency measurements.



3.2 Measurement of specimen thicknesses during induced creep testing and material deformation calculations

The average results of the thickness measurements during the induced creep test, the calculation of the deformations for each sample, and the absolute and percentage compressibilities are presented in Table 4. The compressibility (c) is calculated by the absolute difference between d_L and d_B . It can be observed that rock wool samples # 11 and 12 have the highest compressibility.

Table 4: Average results of thickness measurements during compressibility test and calculation of deformation.

#	Thickness (mm)			Deformations (mm)			
	d_L	d_F	d_B	$d_L - d_F$	$d_F - d_B$	c	$c \%$
1	5.0	4.5	4.2	0.5	0.3	0.81	16
2	32.8	30.4	29.7	2.4	0.7	3.13	10
3	4.8	4.3	4.1	0.4	0.3	0.70	15
4	4.0	3.5	3.3	0.5	0.2	0.68	17
5	4.8	3.2	3.0	1.6	0.2	1.8	37
6	7.5	6.7	6.5	0.8	0.3	1.0	14
7	8.5	7.6	7.2	0.9	0.4	1.3	15
8	5.0	4.5	3.7	0.6	0.8	1.3	26
9	5.1	4.8	4.6	0.3	0.2	0.5	9
10	5.2	4.9	4.8	0.3	0.1	0.4	8
11	43.2	19.4	7.3	23.8	12.1	35.9	83
12	57.6	37.2	16.9	20.4	20.3	40.7	71
13	59.8	51.8	34.7	8.0	17.1	25.2	42
14	74.6	61.6	50.5	12.9	11.1	24.0	32

3.3 Regression Analysis Results

In the regression analysis, it was initially verified that the constants obtained for the equation did not result in a satisfactory statistical significance level (less than 95%). It was observed that the rock wool samples, which have open cells and high compressibility, namely samples # 11, 12, 13 and 14 were responsible for generating these inconsistent constants. Thus the regression analysis was redone only with samples # 1 to 10 this time resulting in a statistical significance level greater than 95%. Then, Equation 3 was obtained from the first analysis to estimate the thickness d_B in mm.

$$d_B = -0.78 + \frac{0.09}{11} f_{r,F} + 0.995 \cdot d_F \quad (3)$$



A second regression analysis was performed, this time only with the rock wool samples, # 1 to 14. And Equation 4 was obtained for this set, with a statistical significance greater than 95%.

$$d_B = -54.27 + 3.98 \cdot f_{r,F} + 0.66 \cdot d_F \quad (4)$$

Where:

$f_{r,F}$ must have its input value in Hz;

d_F must have its input value in mm;

d_B must have its input value in mm;

Estimated calculations were made using Eq. 3 for samples # 1 to 10, and Eq. 4 for samples # 11 to 14. The results of the measured d_B and estimated d_B were compared to each other for each sample and the results are presented in Table 5 and also in graphical form being divided into two graphs: the graph in Figure 3 presents the low d_B samples and the graph in Figure 4 presents the high d_B samples, for easy visualization due to the high thickness difference between the samples.

Table 5: Results of measured d_B and d_B estimated using the proposed equation

#	Measured d_B (mm)	Estimated d_B (mm)
1	4.2	4.3
2	4.1	4.0
3	3.3	3.1
4	3.0	3.0
5	6.5	6.4
6	7.2	7.2
7	3.7	4.2
8	4.6	4.5
9	4.8	4.6
10	7.3	6.3
11	29.7	29.7
12	16.9	17.0
13	34.7	38.3
14	50.5	47.4

Figure 3: Graph comparing the results of measured d_B and d_B estimated using the proposed equation for the low d_B samples

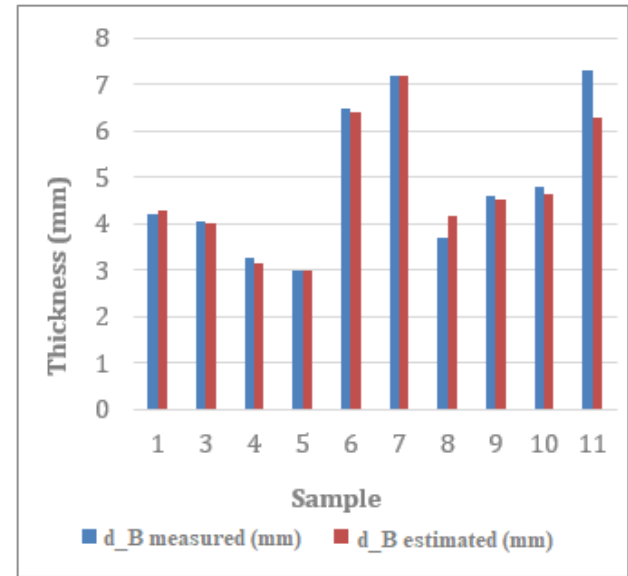
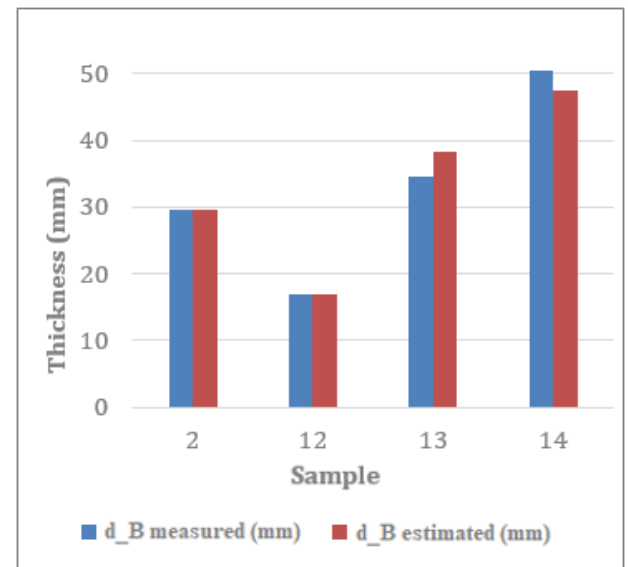


Figure 4: Graph showing the comparison of the results of measured d_B and d_B estimated using the proposed equation for the high d_B samples.



To verify the accuracy of the estimates, the standard deviations of the d_B measurements of each sample were calculated, including in the calculations the measurement of each dial gauge of each specimen, the absolute deviations between the averages of the measured d_B and the estimated d_B and the difference between the standard and absolute deviation were also calculated. Values greater than 0 show that the absolute deviation is within the standard deviations. These results are shown in Table 6.

It can be verified that: the estimates obtained through Eq. 3, applied to the samples # 1 to 10, were less than the standard deviations for 8/10 of the samples; the estimates obtained through Eq. 4, applied to the samples # 11 to 14, were less than the standard deviations for 3/4 of the samples.

These results show that the proposed Equations have satisfactory approximations for the products studied. Regarding Eq. 4, the number of samples included in the source analysis was small, therefore further investigations should be carried out with a larger number of rock wool samples with more variations in thicknesses and densities to obtain greater accuracy in the analysis.

Table 6: Results of the calculations of standard deviation and absolute difference between measured and estimated d_B for each sample.

#	Standard deviation measured d_B (mm)	Absolute deviation between measured and estimated d_B (mm)	Difference between St Dev and Abs Dev (mm)	Eq.
1	0.1	0.1	0.0	(3)
2	0.4	0.0	0.4	
3	0.1	0.1	0.1	
4	0.1	0.1	0.0	
5	0.2	0.0	0.1	
6	0.0	0.1	-0.1	
7	0.3	0.0	0.3	
8	0.2	0.5	-0.3	
9	0.0	0.1	0.0	
10	0.5	0.2	0.3	
11	2.1	1.0	1.1	(4)
12	0.7	0.2	0.5	
13	6.1	3.6	2.5	
14	1.2	3.1	-1.9	



4. CONCLUSIONS

With the regression analysis performed with the results of the resonance frequencies and thickness of the specimens after application of the load of 2 kPa and the thickness after application and removal of the additional load of 48 kPa, there was a significant relation between these properties. The two resulting equations make it possible to satisfactorily estimate the material thickness that would be obtained after the application and removal of the additional load of 48 kPa, from the resonance frequency and the material thickness obtained after the application of 2 kPa, for the materials studied. This shows that the proposed procedure based on the method of Schiavi et al. [7] allows a satisfactory estimation and can be used in preliminary analyses. However, it is necessary to continue the research with a larger quantity of products to improve the equations, especially for the rock wool, varying the thicknesses and densities.

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