DETERMINATION OF ATTENUATION INDEX CURVE "$R_i(f)$" FOR HOMOGENEOUS DOUBLE LOCKING ELEMENTS

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Abstract - The paper is structured in three parts.
In the first part of the paper, are presented some theoretical notions regarding the sound, noise, the sound insulations materials.
Also in the first part of the paper are presented some characteristic regarding the insulation materials and there effects.
In the second part it is described an calculation example for a homogeneous wall with double structure in order to determine the attenuation index curve "$R_i(f)$".
The example calculation contains 10 steps that must be followed and the final results are presented in table 7 and figure 3.
The last part of the paper is represented by conclusions, where the authors tried to explain the importance of the curve "$R_i(f)$" for reducing the noise in the buildings.

Keywords: building elements, insulating materials, acoustic materials, attenuation index curve.

1. INTRODUCTION

Sound insulation is a barrier against the propagation of sound, a certain level of pressure, to another place where the sound pressure level is lower.

Achieving effective insulation assemblies requires knowledge of the propagation of sound vibrations in buildings.

Between the emission source and the observer's ear, sound vibrations can follow two different paths resulting noise or air sound (emitted directly into the air) and noise impact or shock produced by contact more or less violent between two bodies. [6]

There are basically two ways to combat noise:
- sound absorption in air space to prevent or reduce minimum sound propagation from the source to the receiver and thus the noise in the room.
- acoustic insulation reduces sound transmission from room to room another.[6]

It is known that since the beginning of "construction industry", masonry have had an important role in the balance of constructive solutions.

If during the start, solutions consisted mainly in construction of buildings in construction systems using stone masonry, at present there is a large diversification and specialization regarding the masonry materials.

Thus, in time appeared a wide variety of building materials, materials that can be of several types, namely: masonry materials, binders, aggregates, waterproofing materials, insulation materials, acoustic materials, finishing materials. [4]

Insulating materials - these are materials that have great importance in building construction, these are materials that are used to cover / insulate areas in order to protect the constructions elements against of special action environmental factors such as cold, water, wind, etc., that may cause degradation. In this order, to protect buildings and increase comfort, are realized different insulation works.

These insulation works are:
• waterproof insulation or waterproofing which are designed to prevent water penetration into the building or construction elements;
• thermal insulation or thermal insulation which are designed to reduce heat loss through building elements so that inside the building to achieve thermal comfort conditions;
• soundproofing that is designed to dampen sound transmission through building elements and systems in order to achieve acoustic comfort conditions. [4]

The overlap of the external-noise of traffic, in inner-TV, impact (in steps or falling objects) or building facilities with frequencies and amplitudes varying disturbances occur in metabolism and activity aware of: 10 dB doubles the perceived loudness. [5]

Since June 2002 there was a directive requiring the management of urban environmental noise: noise level monitoring in large agglomerations – and the maximum level is around 50 dB.

Municipalities from major cities will have to make noise maps, and the establishment of new residential areas will take into account the noise level of neighbourhoods, and traffic will be redirected. [5]

In the tables below are presented the permissible values for translating data outside the range of audibility of the resonance frequency and attenuation of sound waves which enter:

In table 1 are presented the sound intensity for different places depending on day and night.

Table 1. Allowable noise level outside [db] [5]

Place, area	Intensity	
	day	night
In the vicinity of housing	55	40
Resorts and treatment	45	35
Industrial Area	65	45

Table 2 contains some values for maximum noise levels that governed interior areas.

Table 2. Maximum noise levels governed for interior [db] [5]

Luggage	Allowable amount
Living Rooms	35
kitchen	38
Reading rooms	40
Offices, classrooms	45
Ambient Music	60
stores	70
Technical areas (pumping stations, boilers etc.)	85

2. BUILDING ACOUSTICS

The sound absorption coefficient of a material is $\alpha = (1 - r)$, where r, the sound energy reflection coefficient, is the ratio of sound energy reflected from the surface of the material to that incident upon it.

Values for a specific material depend upon frequency and upon the angle of incidence of the sound. When the sound field is approximately diffuse the corresponding quantity is denoted by α_s; this may be determined in accordance with BS 3638:1987.

The values in the table overleaf have been taken from Evans and Bazley (1978) which predates the current standard.

Absorption depends on mounting and other details of construction and the following values should be regarded only as typical. [7]

Table 3 presents the reverberation absorption coefficients for different materials, depending on their thickness.

Table 3. Reverberation absorption coefficients

Material	Thickness (mm)	Frequency/Hz					
		125	250	500	1000	2000	4000
Acoustic plaster	13	0.15	0.20	0.35	0.60	0.60	0.50
Acoustic tiles (perforated fiberboard)	18	0.10	0.35	0.70	0.75	0.65	0.50
Asbestos (sprayed)	25	0.10	0.30	0.65	0.85	0.85	0.80
Brickwork	—	0.02	0.02	0.03	0.04	0.05	0.07
Carpet. Axminster)	8	—	0.05	0.15	0.30	0.45	0.55
Carpet on underlay	14	—	0.05	0.20	0.40	0.60	0.65
Curtain (velour, draped)	—	0.14	0.35	0.55	0.72	0.70	0.65
Glass fiber (resin-bonded9	25	0.10	0.25	0.55	0.70	0.80	0.85
Glass wool (uncompressed)	25	0.10	0.25	0.45	0.60	0.70	0.70
Mineral wool	25	0.10	0.25	0.50	0.70	0.85	0.85
Polystyrene, expanded (rigid backing)	13	0.05	0.05	0.10	0.15	0.15	0.20
Polystyrene, expanded (on 50 mm battens)	13	0.05	0.15	0.40	0.35	0.20	0.20
Polyurethane foam (flexible)	50	0.25	0.50	0.85	0.95	0.90	0.90
Snow	25	0.15	0.40	0.65	0.75	0.80	0.85
Wood panelling (oak, on 25 mm battens)	13	0.20	0.10	0.05	0.05	0.05	0.05

Insulation against airborne noise.

The sound reduction index (R) is the ratio of sound energy incident on a partition to that which is transmitted through it, expressed in decibels (BS 2750: 1980).

The values vary with frequency and angle of incidence; for comparative purposes a single value (R_w) can be derived from the data over the frequency range 100–3150 Hz according to BS 5821: Part 1: 1984. Although mass is the main determinant of R above the resonant frequency, the relationship is not a simple one, due to 'coincidence' effects associated with flexural waves in the partition (Fahy 1985).

For single, homogeneous partitions, however, the mean value of R over the range 100–3150 Hz can be estimated to be approximately $R_{avg} = 10 + 15 \log_{10}(m)$ dB, where m is the surface mass density in kg m^{-2}.

For some types of partition $R_w \approx R_{avg} + 3$ dB. [7]

3. CALCULATION AND DETERMINATION EXAMPLE OF THE CURVE "$R_i(f)$"

Below it is presented an example in order to determine the attenuation curve indices "$R_i(f)$" for a homogeneous wall with double structure shown in Figure 1.

The structure presented below (figure 1) is composed from: on the exterior plaster mortar, autoclaved aerated concrete, mineral wool, masonry clay, air gap.

In order to determine the sound attenuation curve, the structure is divided in two component elements.

First element is composed from: aerated concrete and plaster mortar, and the second: clay masonry and plaster mortar.

For each structure are determinate: the mass per unity area, m, the frequency of coincidence area, (f_B-f_C), the attenuation curves indices, $R_1(f)$ and $R_2(f)$, the final curve R(f), appropriate correction by the flanking sound transmission, ΔRa, the correction ΔRa, the ΔR_{b1}correction, the ΔR_{b2} correction and is stabilization the calculated frequencies string "$f_{\lambda n}$", ΔR_c, the correction ΔR_c

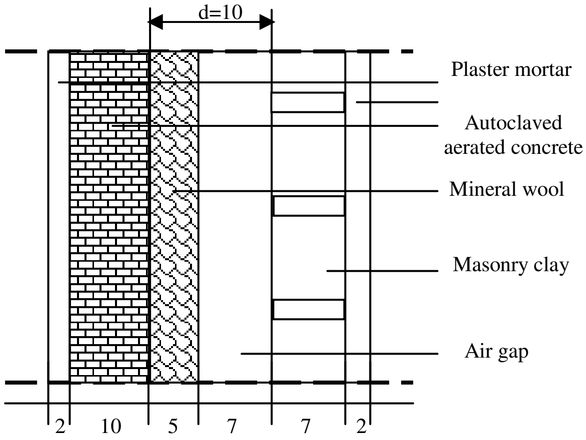

Fig. 1. Homogeneous wall with double structure

Sound attenuation curve indices "Ri(f)" is constructed as follows:

1. First it is calculated the mass per unit area of the building element, "m", [kg/m²];

2. Determine the frequency of coincidence area overlapping (f_B-f_C) by using the relationships presented in the table 3. From the same table, it is determine the value of the attenuation in the area of coincidence "R_B = R_C", depending on the product which is made of the construction element;

Table 3. The frequency of coincidence area

Product	R_B=R_C [dB]	f_B [Hz]	f_C [Hz]
Concrete, reinforced concrete	38	$\frac{19000}{m}$	$\frac{85000}{m}$
Clay masonry elements	37	$\frac{17000}{m}$	$\frac{77000}{m}$
Autoclaved aerated concrete	29	$\frac{6700}{m}$	$\frac{43000}{m}$
Plaster	25	$\frac{5000}{m}$	$\frac{38000}{m}$
glass	27	$\frac{5300}{m}$	$\frac{53000}{m}$
wood Products	19	$\frac{2100}{m}$	$\frac{13600}{m}$

In Table 4 are centralized the values determined for the mass per unit area of the component elements.

Table 4. Mass per unit area of the building element, "m", [kg/m²]

Component element 1 - Autoclaved aerated concrete and plaster mortar	**Component element 2 –** Clay masonry and plaster mortar
m_1 = 0,10×650 + 0,02×1700 = 99 kg/m²	m_2 = 0,07×1800 + 0,02×1700 = 160,5 kg/m²
R_B = R_C = 29 dB	R_B = R_C = 37 dB
$f_B = \frac{6700}{99} = 67{,}67 Hz$	$f_B = \frac{17000}{160} = 106{,}25 Hz$
$f_C = \frac{43000}{99} = 434{,}34 Hz$	$f_C = \frac{77000}{160} 481{,}25 Hz$

3. It is determine for the two components elements, simple, the attenuation curves indices R_1(f) and R_2(f);

4. Is constructed the curve R (f) = R_1 (f) + R_2 (f);

5. It is determine the final curve R(f) using the relationship:

$$R_i(f) = R(f) + \Delta R_a + \Delta R_{b1}(f) + \Delta R_{b2}(f) + \Delta R_c \text{ (dB)} \qquad (1)$$

where:

ΔRa – appropriate correction by the flanking sound transmission,[dB];

ΔRb_1 – sound absorption corresponding to the adjustment of the gap between the two simple constituents elements, [dB];

ΔRb_2 – the corresponding adjustment to stabilize the standing waves in the space between the two simple constituent elements, [dB];

ΔRc – appropriate correction mechanical coupling of the two simple constituents elements, [dB].

In the table 5 is presented the ratio between the "df" - thick sound absorbing treatment and "d" - the distance between the two simple constituent elements.

Table 5.The ratio between df and d

d_f / d	0	0,25	0,35	0,50	0,70	0,85
Δf	6	4	3	2	1	0

The correction "ΔRa" is determined using the relationship:

$$\Delta R_a = -40\, lg\left(\frac{Z_{m1} + Z_{m2}}{Z_{m,med}} + 1\right) \text{[dB]} \qquad (2)$$

6. Is introduced the effect of noise by flanking transmission, moving curve "Ri(f)" value constructed in section 3:

$$\Delta R_a = -20\, lg\left(\frac{Z_{m1}}{Z_{m,med}} + 1\right) \qquad \text{[dB]} \qquad (3)$$

where:

Z_m - mechanical impedance corresponding to the construction element considered, [daN/m³];

$Z_{m,med}$ - average mechanical impedance of the adjacent building components delimiting the receiving space of the element considered, [daN/m³].

The ratio can be calculated approximately using the relation, which can be written:

$$\frac{Z_m}{Z_{m,med}} = \frac{m \cdot P}{\sum m_i^{'} \cdot l_i} \qquad (4)$$

where:

m - mass per unit area of the considered building element, [kg/m²];

P - perimeter of the considered building element, [m];

I - the mass per unit area adjacent of the building element "i", [kg/m²];

li - contact side length of the adjacent building element "i" element considered, [m].

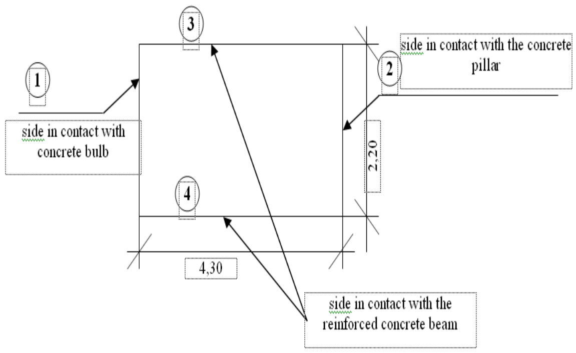

Fig. 2. Detailing the size of the building components

$$l_1 = l_2 = 2{,}20m \quad \Rightarrow \quad l_3 = l_4 = 4{,}30m$$

$\eta_1 = \eta_2 = 0{,}8$
$m'_1 = m'_2 = 0{,}50 \times 2500 = 1250$ kg/m²
$m'_3 = m'_4 = 0{,}60 \times 2500 = 1500$ kg/m²

7. Determine the correction ΔRa:

$$\Delta R_a = -40\, lg\left(\frac{Z_{m1} + Z_{m2}}{Z_{m,med}} + 1\right) \tag{5}$$

$$\frac{Z_{m1} + Z_{m2}}{Z_{m,med}} = \frac{P(\eta_1 m_1 + \eta_2 m_2)^{1,3}}{\sum_{i=1}^{4} m_i^{'} \cdot l_i} \tag{6}$$

where:
$Z_{m1,2}$ - mechanical impedances for each of the two simple constituents elements daN/m³;
$m_{1,2}$ - mass per unit area of each of the two simple constituents elements, kg/m^2;
m'_i - mass per unit area adjacent element "i" in kg/m²;
$\eta_{1,2}$ - coefficients which take into account of how are mounting the simple clamping elements constituent to the adjacent building; (η = 1.0 for embedding; η = 0.8 for articulation).

$$\frac{P(\eta_1 m_1 + \eta_2 m_2)^{1,3}}{\sum_{i=1}^{4} m_i^{'} \cdot l_i} = \frac{2 \times (2{,}20 + 4{,}30)(0{,}8 \times 99 + 0{,}8 \times 160)^{1,3}}{2(1250 \times 2{,}20 + 1500 \times 4{,}30)}$$

$$= \frac{13 \times 207{,}2^{1,3}}{2 \times 9200} = \frac{1334289}{18400} = 0{,}725$$

$\Delta R_a = -40$ lg $(0{,}725 + 1) = -40 \times 0{,}236 \approx -9{,}5$ dB

8. Calculate the ΔR_{b1}correction:

$$\Delta R_{b1} = -10\, lg\, \frac{1}{\alpha_m} \tag{7}$$

Values are calculated in Table 6, considering α (f) for the two products bordering the air layer, respectively autoclaved aerated concrete plaster and high density mineral wool (140 kg/m^3).

Table 6. Values for α (f)

α_m(f)	ΔR_{b2}(f), dB
< 0,10	- 6
0,10 ... ≤ 0,25	- 4
0,25 ... ≤ 0,50	- 2
>50	0

9. Calculate the ΔR_{b2} correction and is stabilization the calculated frequencies string "$f_{\lambda n}$" with the relationship:

$$f_{\lambda 1} = \frac{17000 \times n}{d}, \text{ d = 10 cm}$$

$$f_{\lambda 1} = \frac{17000 \times 1}{10} = 1700$$ Hz (correction is made in the right frequency of 1600 Hz)

$$f_{\lambda 1} = \frac{17000 \times 2}{10} = 3400$$ Hz ⇒ outside the useful frequency

Because at f = 1600 Hz, $\alpha_m > 0{,}50$ results that $\Delta R_{b2} = 0$, according to the values given in Table 5.

10. Determine the correction ΔR_c

$m_1 + m_2 = 99 + 160 = 259$ kg/m^2 > 250 kg/m^2

$$\Rightarrow k_1 = \frac{1{,}2}{d} \cdot 10^4 = \frac{1{,}2}{0{,}1} \cdot 10^4$$

$$f_0 = \frac{1}{2}\sqrt{k_1\left(\frac{1}{m_1} + \frac{1}{m_2}\right)} = 0{,}5\sqrt{\frac{1{,}2}{0{,}1} \times 10^4 \left(\frac{1}{99} + \frac{1}{160}\right)} = 44{,}15$$

$$\cong 44 Hz$$

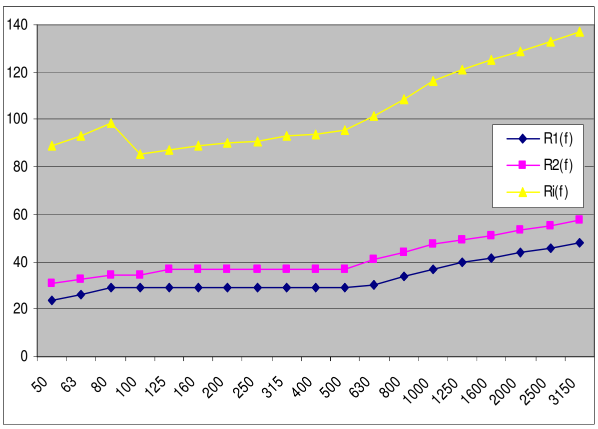

Fig. 3. Variation curves R_1 (f), R_2 (f), R_i (f)

Table 7.

Frequency	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150
R1(f)	24	26	29	29	29	29	29	29	29	29	29	30,4	33,8	37	39,8	41,8	43,8	45,8	47,8
R2(f)	30,7	32,7	34,7	34,7	37	37	37	37	37	37	37	41	44	47,3	49,3	51,3	53,3	55,3	57,3
R=R1+R2	54,7	58,7	63,7	63,7	66	66	66	66	66	66	66	71,4	77,8	84,3	89,1	93,1	97,1	101	105,1
ΔRa	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5	-9,5
R+ΔRa	45,2	49,2	54,2	54,2	56,5	56,5	56,5	56,5	56,5	56,5	56,5	61,9	68,3	74,8	79,6	83,6	87,6	91,6	95,6
αBCA				0,02	0,02	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,03	0,03	0,04	0,04	0,05	0,05
αv,m				0,08	0,08	0,12	0,16	0,2	0,35	0,4	0,65	0,7	0,82	0,94	0,96	0,98	1	0,96	0,98
αm				0,05	0,05	0,07	0,09	0,11	0,19	0,21	0,34	0,37	0,43	0,49	0,5	0,52	0,52	0,52	0,52
1/αm				20	20	14,29	11,111	9,091	5,263	4,76	2,94	2,7	2,326	2,041	2	1,92	1,92	1,92	1,923
log10(1/αm)				1,3	1,3	1,155	1,0458	0,959	0,721	0,68	0,47	0,43	0,367	0,31	0,3	0,28	0,28	0,28	0,284
ΔRb1				-13	-13	-11,55	-10,46	-9,586	-7,212	-6,8	-4,7	-4,3	-3,67	-3,1	-3,01	-2,84	-2,84	-2,84	-2,84
R+ΔRa+ΔRb1	45,2	49,2	54,2	41,2	43,5	44,95	46,042	46,91	49,29	49,7	51,8	57,6	64,63	71,7	76,6	80,8	84,8	88,8	92,76
ΔR_{b2}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R_c	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
Ri(f) = R(f) + ΔRa + +ΔRb1(f) + ΔRb2(f) + ΔRc	**89,2**	**93,2**	**98,2**	**85,2**	**87,5**	**89**	**90,04**	**90,91**	**93,29**	**93,7**	**95,8**	**102**	**108,6**	**115,7**	**121**	**125**	**129**	**133**	**136,8**

4. CONCLUSION

Reducing noise in buildings can be done by using sound absorbing materials which are obtained by suspending or application on construction elements bounding surface of bodies of porous material, which forms a surface as large sound absorption.

Oscillating plate absorbers method relies on the fact that a body / panel acoustic waves vibrate in the way of consuming part of the incident acoustic energy. If the frequency sound waves coincide with the absorbent system, reaching the phenomenon of resonance, acoustic absorption is maxim.

Absorbing acoustic treatments such panels can be made from plywood, cardboard, metal, or wood frames fitted with a thick cloth and a porous material (cotton wool). Type plate absorbents can be mounted with free space in the back or felt.

Also, it can be improved the absorption capacity by partitioning the space behind the panel with rods and strips of felt or wool.

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