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CERTAIN PROBLEMS OF NOISE ANNOYANCE*

AURELIAN STAN

Acoustical Committee, Rumanian Academy of Sciences
Calea Victoriei 125, Bucharest, Romania

Of many objective and subjective problems connected with noise annoyance the present paper presents the results of investigations concerning the following issues:

1. Dependence of the effectiveness of an acoustic baffle on the kind of closed space in which it has been placed.
2. Economic effects of measures taken to diminish noise inside a closed space.
3. Correlation between certain annoyance indices TNI and LNP and σ, and the presentation of results of statistical traffic noise measurements.

Many theoretical and experimental works have discussed the diminution of the sound level by acoustic baffles placed in free space. It seems sufficient to mention here only a synthetic review work [1] and the proceedings of a seminar on the acoustic protection of residential zones with baffles [2]. Much less research has been devoted to baffle activity in closed rooms [3-5]. In order to determine baffle efficiency in open and closed spaces, one should consider equation (1) for the baffle attenuation in a free field,

$$\Delta L_e = 10\lg\frac{|P_E^2|}{P_D^2} = 10\lg\frac{4}{N^2} = 6 - 10\lg N^2, \tag{1}$$

where P_E and P_D are the acoustic pressures measured at the same point with baffle and without it,

$$N^2 = \{[C(u_2)-C(u_1)]^2+[S(u_2)-S(u_1)]^2\}\times$$
$$\times\{[C(v_2)-C(v_1)]^2+[S(v_2)-S(v_1)]^2\}, \tag{2}$$

$$u = y\sqrt{\frac{2}{\lambda}\cdot\frac{1}{x_r}},\quad v = z\sqrt{\frac{2}{\lambda}\cdot\frac{1}{x_r}},$$

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* FASE-78, invited paper, unpublished in the Proceedings.

C and S being the Fresnel functions, u and v – the Fresnel parameters and x_r – the distance (Fig. 1) defined by the relation

$$\frac{1}{x_r} = \frac{1}{x_s} + \frac{1}{x_0}$$

and λ denoting the wavelength.

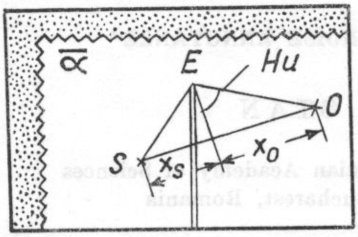

Fig. 1. A baffle in a closed space

In a closed space the insertion attenuation of a baffle E placed between a source S and an observer O can be expressed [3] by

$$\Delta L_r = 10\lg\frac{I_{\rm d}+I_{\rm rev}}{I_{\rm dif}+I_{\rm rev}}, \tag{3}$$

where $I_{\rm d}+I_{\rm rev}$ is the acoustic intensity measured at an observation point without the baffle, as the sum of the sound intensity from the direct field $I_{\rm d}$ and the intensity from the reverberent field $I_{\rm rev}$, which have the following values:

$$I_{\rm d} = \frac{P}{4\pi(x_s+x_0)^2}, \quad I_{\rm rev} = \frac{4}{\pi}P.$$

The sum of $I_{\rm dif}+I_{\rm rev}$ is the sound level at the same point with the baffle and consists of a diffracted wave field intensity

$$I_{\rm dif} = I_e\left(\frac{x_r}{2x_0}N\right)^2$$

and a reverberent field sound intensity for the changed conditions of $I_{\rm rev}$, I_e being the sound intensity in front of the baffle, P – the sound power of the source, and $R = S\alpha/(1-\alpha)$ is the acoustic absorption of the enclosure (room).

One can thus write relation (3) in the following way:

$$\Delta L_r = 10\lg\frac{4}{N^2}\,\frac{1+4\pi(x_s+x_0)^2/R}{1+16(x_s+x_0)^2/N^2R}. \tag{4}$$

Since equation $10\lg(4/N^2) = \Delta L_e$ is the baffle insertion loss attenuation in a free field (1), relation (4) may be written as

$$\Delta L_r = \Delta L_e - \Delta L_c, \tag{5}$$

where ΔL_c is the insertion attenuation loss correction of a baffle in a closed space:

$$\Delta L_c = 10\lg \frac{1+4\pi(x_s+x_0)^2/R}{1+16(x_s+x_0)^2/N^2} \frac{\varrho}{R} \tag{6}$$

From relation (6) one can draw the following conclusions:

a. In an anechoic chamber ($\alpha = 1$, $R = \infty$), $\Delta L_c = 0$, the acoustic conditions correspond to those in a free field in which

$$L_r = L_e. \tag{7}$$

b. In the case of a reverberent space ($\alpha = 0$, $R = 0$)

$$\Delta L_c = -10\lg \frac{4}{N^2} = \Delta L_e,$$

therefore $\Delta L_r = 0$, and thus the baffle causes no additional attenuation.

In order to show changes in the attenuation correction for a semi-infinite baffle placed in a semi-reverberent chamber, the value of this parameter was calculated for various values of R in the range of 50-1000 m² and for different distances SO between the source and the observer, $SO = x_0 + x_s$ in the range of 2-14 m. The results of these calculations are shown in Figs. 2 and 3. The values calculated for the expression N^2, as a function of the parameter V, are given in Table 1.

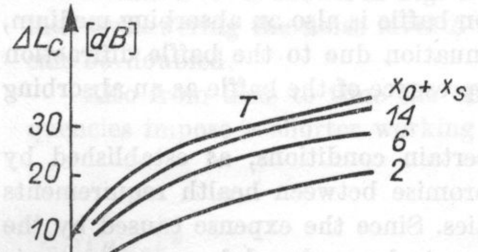

Fig. 2. Correction ΔL_c as a function of the parameter V, $R = 1000$ m²

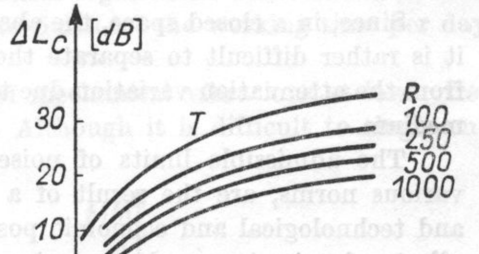

Fig. 3. Correction ΔL_c as a function of V for $x_s + x_0 = 2m$ and various values of R

It follows from Fig. 2 that for given values of R and V the correction ΔL_c increases with increasing distance between the source and the observer, whereas

Table 1. Values calculated for the expression N^2 as a function of the parameter V

V	1	2	3	4	5	6	7	8	9	10	11
N^2	0166	0050	00224	00126	000795	00055	000417	000316	00251	000198	000158

it follows from Fig. 3 that for a fixed distance SO and a given value of V, the correction ΔL_c decreases with increasing R. Fig. 4 shows the attenuation variation ΔL as a function of various parameters. Thus, for long distances between the source and the observer, the attenuation is almost independent of the acoustic absorption of a room, whereas for, short distances x_0+x_s, the attenuation ΔL increases rapidly with increasing R.

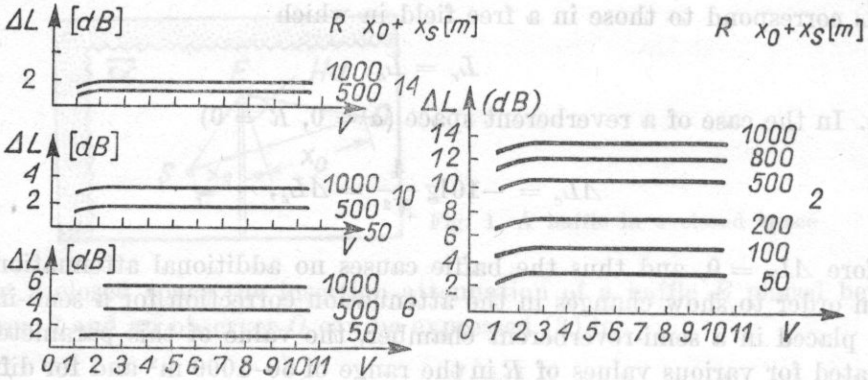

Fig. 4. Attenuation correction ΔL as a function of V, R, for various distances between the source and the observer

Since, in a closed space, the absorption baffle is also an absorbing medium, it is rather difficult to separate the attenuation due to the baffle diffraction from the attenuation variation due to the presence of the baffle as an absorbing medium.

The admissible limits of noise in certain conditions, as established by various norms, are the result of a compromise between health requirements and technological and economic possibilities. Since the expense caused by the effects of noise is very large, noise also has to be analyzed from an economic point of view. There are general, direct and indirect expenses [7-9], including:

expenses for the periodic checking of the level of noise and vibration in different places of work, comprising the cost of adequate apparatus and trained personnel;

time wasted by skilled personel who are employed in medical check up, as well as the shortage and variation of staff due to the changing of jobs to those that are less noisy;

a loss of capital invested in the former and new jobs;

sums paid as allowances for work in very noisy conditions, premature pensions or damages for possible accidents on the job due to the effect of noise and vibration.

These sums should be enlarged by losses due to a lower output on the job and a poorer quality of product. There are still a number of machines and equipment whose operational noise cannot be lowered to the limits established by the various norms without large expense. The cost of solutions leading to improving the acoustic conditions of such a job may be represented as the cost of diminishing the noise by 1 dB as a result of the solution adopted or by comparison of the expense necessary to lower the noise and vibration level to the overall investment cost.

It seems that in the analysis of economic issues other factors should also be considered, e.g. the diminished percentage of hearing loss risk (Fig. 5), the increase of effective working time due to diminished noise, and increased production following increased individual output. The measures taken to lower the level of equivalent noise decrease the hearing loss risk, which has not only social, but also economic significance.

The admissible value of the noise level for an 8-hour day is known to be the level L_{eq} equal to 90 dB(A). If the noise level $L > 90$ dB(A) for 8 working hours, the time of exposure to noise should be shortened to make the danger to hearing the same as that at 90 dB(A).

The relation between the noise level L and the exposure time t, in hours, can be expressed by

$$L = L_{\mathrm{eq}} + \Delta L = 90 + k \lg \frac{8}{t}, \tag{9}$$

where $10 \leqslant k \leqslant 20$.

Relation (9) is shown in Fig. 6 on a linear-logarithmic scale. It can be seen that by lowering the noise level L by 3 to 5 dB(A), the working time per day can be doubled.

Also from time to time the effects of mechanical vibrations at lower frequencies impose a shorter working time. Although it is difficult to single out

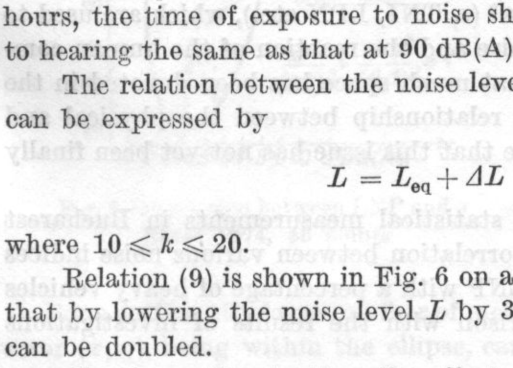

Fig. 5. The variation of the hearing loss risk

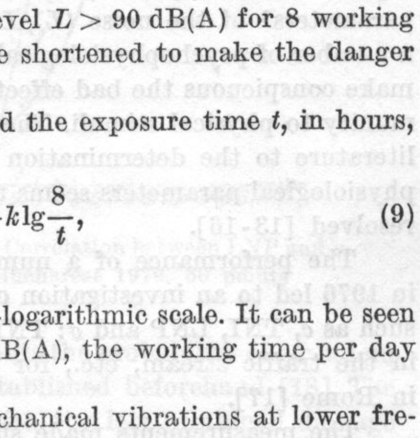

Fig. 6. Relation between the noise level L and the admissible working time t

productivity from the set of factors occurring in the process of material production, nevertheless, our investigations have given some interesting results concerning this issue. Thus, in a weaving plant room, where the total noise intensity was 100 dB, an increase in productivity of 2-3% was achieved, together with working time lengthened by over 3 hours.

In summary, it should be stated that in order to correctly estimate the economic efficiency of the measures taken to diminish noise and vibration, one should also take into consideration the increased production due both to a higher productivity and a longer working day in the noise, as well as the diminished hearing loss risk.

In the analysis of problems posed by transport noise the two following aspects exist: objective, concerning the determination of certain physical parameters[1] of the noise ($L_i, L_{10}, L_{50}, L_{\text{eq}}, \sigma$) and subjective, connected with a number of psychophysiological factors[2] (c, TNI, LPN etc.), which are used to make conspicuous the bad effects of noise and the reaction of the human community to physical stimuli. The fact that much space has been devoted in the literature to the determination of the relationship between the physical and physiological parameters seems to prove that this issue has not yet been finally resolved [13-16].

The performance of a number of statistical measurements in Bucharest in 1976 led to an investigation of the correlation between various noise indices such as c, TNI, LNP and σ: TNI and LNP with a percentage of heavy vehicles in the traffic stream, etc., for comparison with the results of investigations in Rome [17].

The measurements made show that a dependence which is very close to being linear exists between the random variables TNI and σ; and the regression curve, around which experimental data group with greatest probability, can be expressed in the following way: $\text{TNI} = 56.74 + 5.67\sigma$.

Figs. 7 and 8 show the correlative dependencies between LNP and σ, in the form of the regression curves and the relevant ellipses limiting the experimental data obtained the longer axes of which are calculated from the regression curves. The results obtained show that although the average indices of INP in both cases had approximately equal values, the mean square deviations were different. It can be seen that $\sigma_B > \sigma_R$ which indicates a much higher scatter of the results in the first case. It may have been caused by a greater variety of vehicle types, their technical defects or by vehicles travelling without a synchronized traffic light system, the so called "green wave".

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[1] L_i is noise level exceeding respectively i % of the measurement time,

$$L_{\text{eq}} = 10\lg[\Sigma f_j 10 L_j/10], \text{ where } f_j = \left(\sum t_j\right)/T,$$

$\sum t_j$ being the total time for which the noise level belongs to class j, and T — the total measurement time.

[2] $c = L_{10} - L_{90}$; $\text{TNI} = L_{90} + 4c - 30$; $\text{LNP} = L_{50} + c + c^2/50$.

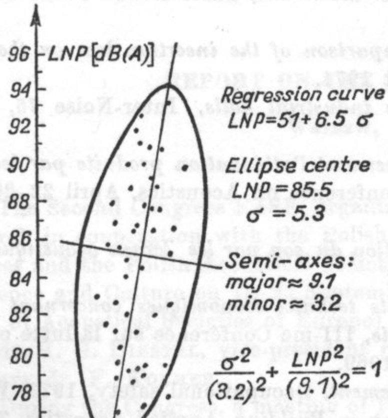

Fig. 7. Correlation between LNP and σ, Rome 1974, 46 points

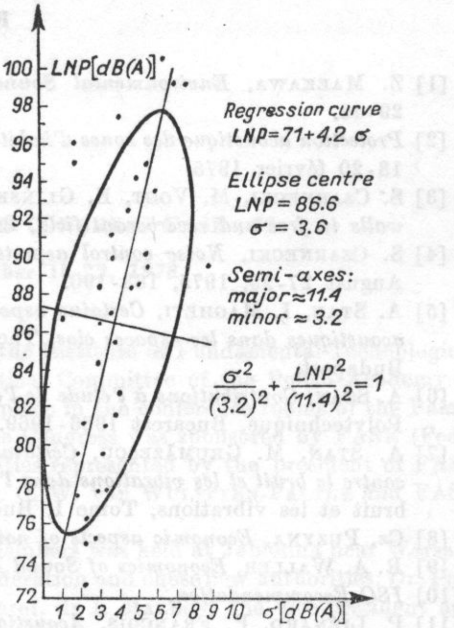

Fig. 8. Correlation between LNP and σ, Bucharest 1976, 60 points

For a sufficiently large number of measurements the probability of a random vector (x, y), being within the ellipse, can be established beforehand [18]. The results of investigation show good agreement with the law combined damage index R and equivalent sound level L_{eq} [19, 20]:

$$R = -11+8.3\lg L_{\mathrm{eq}}. \tag{10}$$

Fig. 9 shows how the percentage of people annoyed by the traffic noise changes with increasing L_{eq}.

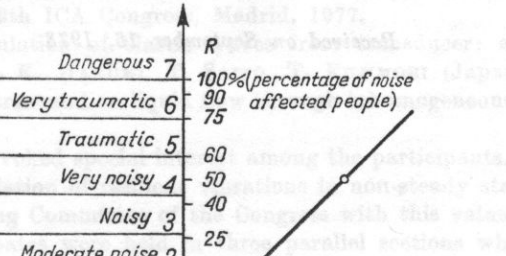

Fig. 9. The damage index R as a function of L_{eq}

References

[1] Z. Maekawa, *Environmental Sound Propagation*, ICA 8 (1974), Invited Lectures, 29-46.

[2] *Protection acoustique des zones d'habitation par des écrans*, Table Ronde CNRS Marseille, 18-20 février 1975.

[3] S. Czarnecki, M. Vogt, E. Glińska, *Comparison of the insertion loss on the barrier walls in free and reverberant field*, Budapest 1974.

[4] S. Czarnecki, *Noise control aspects inside industrial halls*, Inter-Noise 75, Sendai, August 27-29, 1975, 183-190.

[5] A. Stan, I. Magheti, *Certains aspects concernant l'atténuation produite par les écrans acoustiques dans les espaces clos*, The 6th Conference on Acoustics, April 22-26, 1976, Budapest.

[6] A. Stan, *Contributions à l'étude de l'atténuation du son par les écrans acoustiques*, Inst. Polytechnique, Bucarest 1966-1969.

[7] A. Stan, M. Grumăzescu, *Certains aspects technico-économiques concernant la lutte contre le bruit et les vibrations dans l'industrie*, III-me Conférence sur la lutte contre le bruit et les vibrations, Tome I, Bucarest 1969.

[8] Cz. Puzyna, *Economic aspects of noise abatement*, Occupational safety, 1973, Warsaw.

[9] R. A. Waller, *Economics of Sound Reduction in Building*, Applied Acoustics, 7 (1968).

[10] *ISO-Recommendation.*

[11] P. Liénard, P. François, *Acoustique industrielle*, Paris 1972.

[12] *ISO-Recommendation*, 2631-1974.

[13] I. D. Griffiths, F. J. Langedon, *Subjective response to rock traffic noise*, Building Research Station, Paper 37, 38, 1968.

[14] D. R. Aubrée, *La gêne causée par le bruit de circulation à Paris*, 7 Congress ICA, Budapest 1971.

[15] G. L. Fuchs, *Objective and subjective evaluation of rooms*, 9 Congress ICA, Madrid 1977.

[16] G. Vulkan, *Traffic noise index*, Journal of Sound Vibration, 11, 475-476.

[17] C. B. Cannelli, *Traffic noise pollution in Roma*, Applied Acoustics, 7, 2 (1974).

[18] A. Stan, T. Stănăsilă, *Quelques aspects concernant le degré de gêne du bruit produit par le traffic*, ETAN XXI Jugosloveńska Konferencija Banja-Luka, 6-10, 1977.

[19] M. de Silva, *Urban noise evaluation*, 9 Congress ICA, Madrid 1977.

[20] R. Gambard, *The Meaning of Correlation Coefficients in Annoyance*, Acoustica, 33, 351-352 (1975).

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