Proceedings of the 7th WSEAS International Conference on Acoustics & Music: Theory & Applications, Cavtat, Croatia, June 13-15, 2006 (pp48-53)

Investigation and Reduction of Ambient Noise in an Urban Area

NICOLAE HERIŞANU, VASILE BACRIA, MIHAI TOADER, SMARANDA POPA RADOVAN
Department of Mechanics and Vibration
University "Politehnica" of Timişoara
Bd.Mihai Viteazu, 1, 300222 Timişoara
ROMANIA

Abstract: - Starting from the reality that urban noise pollution has became a major problem in developed countries in the last two decades, in the present paper this problem was approached in an urban area by analyzing the numerous factors contributing to the environmental noise. The study was performed between 2001 and 2005, comprising noise measurements performed in Timişoara, Western Romania. Beside these measurements, traffic information was collected including traffic flows, traffic speed and composition. A social inquiry was also conducted. Questionnaires were completed in order to assess the annoyance of the inhabitants from various noise sources. A variety of noise mitigation measures was identified and some of them were already applied with the help of local authorities.

Key-Words: noise, mitigation measures, traffic noise in built-up areas

1 Introduction

Noise management in big cities was lately recognized worldwide as an important part of environmental management. In the last decades, urban noise has been increasing rapidly, due to the increase of certain noise sources [5], [8], [9], [10], [11], [12].

Everywhere, on the street, at working place, at home, human being is accompanied ceaselessly of the noise and vibrations.

The noises and vibrations in urban areas are generated by the sources from the industrial installations, construction sites, the road, rail, air and naval transportation means, the technical-sanitary installations in buildings, stadiums, exhibitions and concert zones, the public food units etc.

Preoccupation for noise level measurements in Timişoara city started in 1980, when first measurements were performed by Polytechnic University of Timişoara through a specialized laboratory. In 1981 the problem of noise pollution first received attention at local level. Anyway in that era, noise pollution was a minor problem due to the relatively small number of cars participating in the urban traffic.

As of 1990 the number of private cars in Timişoara continuously increased. This increase was estimated to almost 100% from 1990 to 2005.

A systematic monitoring of noise pollution started in 1992, since the number of cars significantly increased and the urban traffic begins to smother due to improper design of roads, which are too narrow for such increased traffic intensity. Many of the cars were obsolete and obviously produce more noise pollution than advanced cars. Only in the last 6 years restrictions were imposed about importing used cars which produce high noise levels.

2 Environmental noise sources in urban area

Obviously, the main sources of environmental noise were found to be the road, rail and air transportation.

The noise generated by the road transportation is characterized by specific frequency specters, pressures, acoustic levels and variations of these levels in time. The noise depends on the intensity and composition of traffic as well and on the speed of movement and it is generated from three basic sources: the engine, the exhaust system and the contact between the tire and the road.

The railway transportation generate noise and vibrations due to the variation of the speed of movement, the clearance at the rails extremity (joints), the elasticity of the rails, the conicalness,the eccentricity and the deformations of the bandages, the wheel guide on the rails and the brakes and accelerations.

The main source of noise and vibrations of the aircrafts is the propeller and in the case of the modern ones the sources are the jet engines and the turbo propulsions.

The noise and vibrations sources of a ship are: the main and the auxiliary engines, the cooling, oil and combustible pumps, the turbo blows, the fans, the billow blows which generate forced vibrations of the ship etc.

The industrial noise is due to the operations which are performed with diverse units, machine tools, industrial equipment and tools in technological processes requested by the production. The noise generated by these sources in the industrial halls has the values of 80 – 110 dB(A).

On the building sites the environmental noise is generated by pneumatic hammers, mobile compressors, mechanical charges, graders, excavators, pillar beater etc.

An important contribution to the environmental noise has electrical transformers, characterized by 85 dB level.

In buildings, the sources that generate environmental noise are: people chatting, radio receivers, television sets, musical instruments, walking on floors and stairs, door slamming. In addition to these, there are also the sanitary, heating, ventilating and air conditioning installation, elevators and some electric apparatus (vacuum cleaner, sewing machines, washing machines etc.). These ones generate noises having 50-75 dB which disturbs 80% of the lodgers [15].

The noise generated by activities at stadiums, in exhibitions as well as in concert zones has an important contribution to high level environmental noise and cannot be neglected.

Finally, an important contribution to the environmental noise has the activity carried out in the public units of food with or without refrigerating installations.

All these sources were identified in the urban area of Timişoara, were this study was performed.

3 Noxious environmental noise

The environmental noise is extremely injurious to the human beings' life and activity, having several adverse effects. Thus, for the 65 dB equivalent noise level during the day, 45% of the population in the polluted zone is disturbed [15].

The noises affect human beings nervous system generating psycho-psychological and blood circulation modifications as well as sleep disturbances and general annoyance. Also the visual function and endocrine gland are adversely affected. At the same time the noise generates auditory tiredness and sonorous trauma.

In order to reduce the effects of the noise, limit values which cannot be exceeded are established. These limits are characterized by the equivalent noise level and by the noise curves (Cz). The equivalent noise level correspond to an equivalent intensity which could be constant during the whole considered time and is defined by the relation

$$L_{eq} = 10 \lg \left[\frac{1}{T} \int_0^T 10^{0,1L(t)} dt \right] \quad (1)$$

where L(t) is the instant acoustic level.

In this way Romanian standard STAS 10009-88 "Urban acoustic" established the admissible limits of the noise level in urban environment, differentiated on zones and functional endorsements, technical category of streets established on the base of the technical settlements.

Admissible limits are established for noise level of the street (table 1) and in the underground road passages (table 2), noise level at the limit of the functional zones of the urban environment (table 3), noise level inside of the functional zones, of the urban environment (table 4).

Moreover the admissible limits for the interior noise equivalent level in functional civil and socio-cultural units due to some exterior noise sources in accordance to Romanian standard STAS 6156-86 are presented in table 5.

Table 1

Street type (according to STAS 10144-80)	L_{eq} [dB]	C_z [dB]	L_{10} [dB]
I – main	75-85	70-80	85-95
II – linking	70	65	75
III – collecting	65	60	75
IV – local serving	60	55	70

Table 2

Passage zone	L_{eq} [dB]	C_z [dB]	L_{10} [dB]
Passages in tram stations	The values of the street types		
Carriage roads of the passages with length L>200 n on streets of technical category III	-	-	80
Streets of technical category II, I	-	-	90
Pedestrian passages	65	60	-
Underground stations	65	60	-

Table 3

Considered space	L_{eq} [dB]	C_z [dB]
Parks, recreation and rest zones, watering places and climatic treatment zones	45	40
On the precincts of schools, crèches, kindergartens and play spaces for children	75	70
Stadiums, cinemas in open air	65	60
Markets, commercial spaces, restaurants in open air	65	60
Industrial premise	65	60
Parks	90	85
Rail way zones	70	65
Airports	90	85

Table 4

Considered space	L_{eq} [dB]	C_z [dB]
Parks	60	55
Recreation and rest zones, medical and watering places and climatic treatment zones	45	40
On the precincts of schools, crèches, kindergartens and play spaces for children	85	80
Markets, commercial spaces, restaurants in open air	70	65
Stock parks	90	85

Table 5

Building type	Functional unit	L_{eq} [dB]	C_z [dB]
Hospitals	Wards (side-room) 1-2 beds	30	25
	Wards over 3 beds	35	30
Schools	Amphitheaters, classrooms, conference halls	40	35
Technical-administrative buildings	Bureaus of intellectual activities	40	35
Computing centers	Computers halls	55	50
Commercial buildings	Public alimentary units	50	45

4 Theoretical considerations on the acoustic field

During the function of different sources, their vibrations propagate in the surrounding medium as spherical waves and cylindrical waves and at long distance as plane waves.

The differential equation of the spherical waves, in an elastic, homogeneous and isotropic medium with the speed potential ϕ as a parameter is

$$\frac{\partial^2\phi}{\partial t^2} = c^2\left[\frac{\partial^2\phi}{\partial r^2} + \frac{2}{r}\frac{\partial\phi}{\partial r} + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial\phi}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2\phi}{\partial\varphi^2}\right] \tag{2}$$

where r, θ, φ are the spherical coordinates which are positioning the volume element, and c is the travel speed of the wave. The solution of the equation is

$$\phi = \frac{A_c}{r}e^{jk(ct-r)} \tag{3}$$

where A_c is the complex amplitude of the spherical wave, at the frequency $f = \frac{\omega}{2\pi}$ that travels from the source with the speed c and $k = \frac{\omega}{c}$ is the wave number.

The acoustical pressure can be determined with relation [3]

$$p = -\rho_0\frac{\partial\phi}{\partial t} = -j\rho_0\omega\phi \tag{4}$$

If we consider $A_c = Ae^{j\alpha}$, then the acoustical pressure is

$$p = \rho_0\omega\frac{A}{r}\sin(\omega t - kr + \alpha) \tag{5}$$

In the same time, taking into account that some parts of the sources have cylindrical shape, because of their vibrations, there are produced cylindrical waves. These cylindrical waves are characterized by the differential equation

$$\frac{\partial^2\phi}{\partial r^2} + \frac{1}{r}\frac{\partial\phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2\phi}{\partial\varphi^2} = \frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} \tag{6}$$

where ϕ has the known signification, r and φ are the cylindrical coordinates of the volume element.

One solution for this differential equation has the following form

$$\phi = \left[AJ_m(kr) + jBY_m(kr)\right]e^{-jm\varphi}e^{-j\omega t} \tag{7}$$

where A and B are constants, J_m is the Bessel function of the first degree and m range and Y_m is the Bessel-Newman function of the second degree and m range.

In case of the waves that travel uniform, m = 0 and the acoustical pressure can be written

$$p = A\left[J_0(z) + jY_0(z)\right]e^{-j\omega t} \tag{8}$$

where $z = kr = \frac{\omega}{c}r = \frac{2\pi}{\lambda}r$. For small values of the z variable, the expression (8) becomes

$$p = j\left(\frac{2A}{\pi}\right)\ln(kr)e^{-j\omega t} \tag{9}$$

and at an important distance from the source

$$p = A\sqrt{\frac{2}{\pi kr}}e^{j\left[k(r-ct)-\frac{\pi}{4}\right]} \tag{10}$$

Propagation of the spherical and cylindrical waves is causing the variation of the pressure in a point of the acoustical field.

If we consider that the pressure at a moment is p, then the level of the acoustical pressure is

$$L = 20\lg\frac{p}{p_0} \tag{11}$$

where $p_0 = 2 \cdot 10^{-5}$ N/m^2 is the reference acoustical pressure.

In the case of the acoustical wave propagation in the closed spaces considering the case of real rooms, the acoustical wave which forms in the closed space will be damped. The standing damping wave equation is

$$p = P\mathrm{ch}\left[\left(\delta_x - j\omega_x\right)\frac{x}{c} + \varphi_x\right]\mathrm{ch}\left[\left(\delta_y - j\omega_y\right)\frac{y}{c} + \varphi_y\right]\cdot$$
$$\cdot\,\mathrm{ch}\left[\left(\delta_z - j\omega_z\right)\frac{z}{c} + \varphi_z\right]e^{(j\omega-\delta)x} \tag{12}$$

The phase constants φ_x, φ_y, φ_z are determined by the limit conditions x=0, y = 0, z = 0 which must be satisfied.

Using this expression of the acoustic pressure it can be determined the acoustic pressure level in a point of the acoustic field with relation (11).

5 Description of noise measurements

Having in consideration the huge number and variety of sources that have a part to play in generating the environmental noise, as well as the acoustic wave nature produced by these, the acoustic field is extremely complex and its study is indicated to be of an experimental nature.

Noise level measurements were carried out in 113 measuring points which were established near some of the busiest road intersections in Timişoara city.

The measurements have been performed with Brüel & Kjaer 2237 Controller Integrating Sound Level Meter and N.L.-20 Sound Level Meter.

These ones permitted the registering and automatic computing of the main physical indicators of the noise: L_{eq} (equivalent noise level), L_{10} (peak noise level), L_{95} (minimum noise level), L_{50} (average noise level), $L_{0,1}$ (maximum noise level), L_{AE} (exposure level) and $L_{eq\ cum}$ (cumulated equivalent noise level).

These parameters were determined during a continuous period of 8 hours (7.30-15.30), divided in 1 hour time intervals. By means of these measured parameters, it was possible to compute other physical indicators, characterizing the effect of phonic pollution, such as:

- noise climate

$$N.C. = L_{10} - L_{90} \tag{13}$$

- traffic noise index

$$T.N.I. = 4(L_{10} - L_{90}) + L_{90} - 30 \tag{14}$$

- the level of noise pollution

$$L.N.P. = L_{ech} + L_{10} - L_{90} \tag{15}$$

In order to perform the measurements, the microphone was placed on the street pavement edge at 7,5 m distance from the axis of the first runway, at 1,30 m high from the ground.

Simultaneously with the recording of the noise levels, the traffic composition and intensity as well as the speed of the vehicles were determined.

6 Analysis of the results of measurements

Taking account of the importance of the effects of environmental noise in the city of Timisoara it was considered to be necessary the analysis of all aspects concerning the influence of these noises on the human being and the environment. With this aim, the main points of traffic concentration were selected and noise measurements were performed. The values of the equivalent noise level, the admissible level in the measured points, the traffic intensity and the category of the vehicles and trains taking part in the traffic were centralized in a data base designed for the study of the noise pollution in the city of Timisoara. From the obtained data it results that from the 113 measured points in 91 of them (80,53 %) the cumulated equivalent noise exceeds the maximum values allowed by Romanian standard STAS 10009-88, concerning "Urban acoustics". This exceeding was recorded between 0,1 and 16,1 dB. The traffic intensity had values between 9 veh/h and 2681 veh/h and the vehicle speed was found to be between 50 – 60 km/h. The biggest percent of vehicles taking part in the traffic in the measured points was represented by the cars (34,2 % - 95,87 %). The presence in the traffic of big number of trams, trucks, trains and tractors contribute to the increase of the noise level. The deteriorated state and the nature of the road superstructure favored big values of noise level produced by different types of vehicles, in terms of the speed.

In the majority of the measured points the peak noise levels was exceeded with 1-9,5 dB. The 50 dB admitted noise level, measured at 2 m of the building wall, was in general exceeded with 1,3 – 32,9 dB.

The increase of the noise is due primarily to vehicles and trains circulation to the change of displacement direction, to the vehicle passage over the tram rails, to the acceleration and braking. During the displacement of the vehicles in the canyon streets, the increase noise level is produced also by the superposition of the reflected wave on the direct one. The high degree of technical deterioration of some vehicles is an important factor that increases the noise level.

Because in the majority of the intersections where the measurements were performed the admissible limits are exceeded, it is necessary to decrease the noise, whether by the decrease of the vehicle speed limit or whether by restrictions concerning the traffic composition.

Thus for an intersection having the equivalent noise level of 70,2 dB the traffic intensity was 1161 veh/h and

Proceedings of the 7th WSEAS International Conference on Acoustics & Music: Theory & Applications, Cavtat, Croatia, June 13-15, 2006 (pp48-53)

the percent of trucks was 10,1 %. If the trucks are eliminated from the traffic, the noise level will be reduced with 3-4 dB approximately (fig.1), which represents almost the standard admitted value (65 dB).

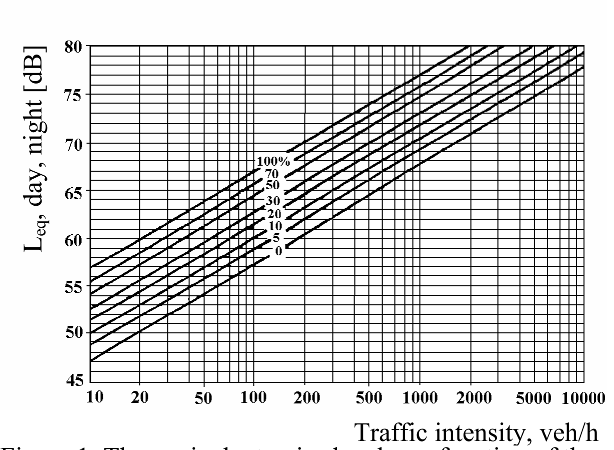

Figure 1. The equivalent noise level as a function of the traffic intensity and truck concentration [14]

If the composition of the traffic is kept to the same parameters, the decrease of the noise level can be obtained by reducing the vehicle speed.

In another intersection with block pavement the cumulated noise level was of 75 dB. If the pavement would be asphalt, then for a speed of 40 – 50 km/h, the noise level would decrease with 5 dB (fig.2) under the admitted value.

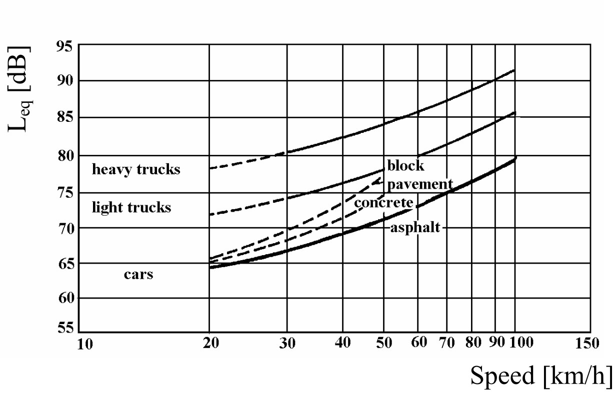

Figure 2. The equivalent noise level as a function of the nature of the way pavement [14]

An attenuation of the noise level can be obtained by the increase of the distance between the inhabited areas and the way and by the creation of the protection areas (green areas). Thus the noise level L_n around the buildings situated at the distance r_n from the way (for sources situated in succession at a distance *s* among them) is given by the relation

$$L_n = L_7 - 20k_s \lg\frac{r_n}{r_7} \qquad (16)$$

if $r_n \le \frac{s}{2}$, and

$$L_n = L_7 - 20k_s\left(k\lg\frac{0,5s}{7} + \lg\sqrt{\frac{r_n}{0,5s}}\right) \qquad (17)$$

if $r_n > \frac{s}{2}$, where L_7 represents the noise level measured at the distance of 7,5 m from the axis of the first runway, k is a coefficient with given value and k_s is a coefficient concerning the specific feature of the ground. For the coefficient k_s are considered the following values: 0,9 for asphalt, 1 for ground and 1,1 for turf. The distance *s* for the transport flows is determined with the relation

$$s = 1000\frac{v_{tr}}{N} \qquad (18)$$

where v_{tr} is the speed in km/h and N the traffic intensity in veh/h.

In conclusion, the main possibilities identified here to decrease the noise level refer to the re-organization and systematization of the traffic, the improvement of the superstructure of the rolling way and speed limitation.

In the same time measurements of sound level inside different types of vehicles were performed. It was measured the noise level existent inside the vehicle at starting, during the motion between the stations and during standings, during a complete route in buses, trolleybuses, tramways, cars in Timisoara city. Table 6 shows the results of these measurements.

Table 6

Type of vehicle	Noise level [dB]		
	At starting	Between stations	In standings
Buses	72-98	62-90	62-80
Trolleybuses	70-94	60-87	60-78
Cars	69-72	65-78	60-63
Old tramways	85-102	68-96	60-85
New tramways	60-82	60-88	51-70

The equivalent sound level has recorded values between 72,9 and 78,6 dB in case of trolleybuses and 71 – 75 dB in case of old tramways made in Romania, respective 68 – 71 dB for the new one imported in Romania from Germany. Following the values of sound level presented in table 6 we observe that the noise inside the vehicles affect more than 80% from passengers and drivers of transport vehicle [15]. To avoid this, it must be taken measures for reducing these noxious. In this case it is necessary to apply new restrictive measures for intensity and composition of traffic the insurance of a corresponding condition of wheels and rail or rolling surface and the permanent verification of technique condition of vehicles. Tramways made in Romania are necessary to be organized with more silent systems for closing doors and the corresponding arrangement of rolling surfaces by assembling some isolating materials between the rail and the sleeper. A corresponding attenuation of noise inside the vehicle can be realized by covering the walls, the ceiling and the floor with sound absorbent materials. In the same time the driver must be able to realize a silent motion of this vehicle.

7 Conclusion

Traffic noise surveying and analysis was performed in the urban area of Timişoara, Romania. Results indicate that main roads of Timişoara are overloaded by traffic flow during working hours and that in 80% of the examined points average noise levels due to road traffic are higher than those set by Romanian noise standards with 0,1 to 16,1 dBA.

In order to decrease the noise generated by the traffic, it was found to be necessary the following actions: organization and systematization of the road traffic, improvement or change of the superstructure of the rolling way of the vehicles, speed limitations, change of some tram tracks, improvement of technical condition of the vehicles, application of a rubber layer between the tram rails and the sleeper, construction of a ring road to avoid the city of Timisoara. Following the recommendation formulated after developing this study started in 2001, local public authorities organized an impressive program aimed at reducing environmental noise in the urban area of Timişoara.

First of all, was decided to completely change the old rail system of the tramway with a modern one, more silent, with better insulation properties. Moreover, all old and noisy Romanian tramways were replaced with a newer generation of tramways, but unfortunately not the newest one. Anyway, these measures already prove to be very effective, offering an important noise reduction.

On the other hand, in order to avoid the presence of heavy trucks in urban area, the construction of a ring road was started. Our estimations conclude that all these will lead to an important improvement of noise condition and traffic safety in urban area of Timişoara. The effects of these measures it follows to be evaluated by new measurements when all the works will be finished.

References:

[1] Darabont A., Văiteanu D., *Combaterea poluării sonore şi a vibraţiilor*, Ed. Tehnică, Bucureşti, 1975

[2] Silaş Gh, Brîndeu L., Toader M., Bacria V., Herişanu N., Stefan C., Jurchela C., Considerations concerning the phonic pollution generated by the road traffic. *Proceedings of First Conference of the Romanian Acoustical Society*, Bucharest, 2001, pp.85-90

[3] Enescu N., Magheţi I., Sârbu M.A., *Acustica tehnică*, I.C.P.E. Publishing House, Bucharest, 1998

[4] Steele C., A critical review of some traffic noise prediction models, *Applied Acoustics*, 62, 2001, pp.271-287

[5] Li B., Tao S., Influence of expanding ring roads on traffic noise in Beijing City, *Applied Acoustics*, 65, 2004, pp.243-24

[6] Heutschi K., A simple method to evaluate the increase of traffic noise emission level due to buildings on a long straight street, *Applied Acoustics*, 44, 1995, 259-274

[7] Mandula J., Salaiova B., Kovala M., Prediction of noise from trams, *Applied Acoustics*, 63, 2002, pp.373-389

[8] Arana M., Vela A., San Martin L., Aramendia E., San Martin R., Evaluation of the percentage of people affected by environmental noise in an urban area, *Eleventh Int. Congress on Sound and Vibr.*, St.Petersburg, Rusia, 2004, pp.1361-1368

[9] Barbaro S., Caracausi R., Chisesi R.M., Cognata G., Acoustic zoning and characterization of the urban area of Sciacca (Italy), *Eleventh Int. Congress on Sound and Vibr.*, St.Petersburg, 2004, pp.1229-1236

[10] Skarlatos D., Drakatos P., Environmental noise-annoyance in Patras, Greece, *Environmental monitoring and assessment*, 11, 2, 1998, pp.171-182

[11] Ali S.A., Tamura A., Road traffic noise mitigation strategies in Greater Cairo, Egypt, *Applied Acoustics*, 63, 11, 2002, pp. 1257-1265

[12] Klæboe R., Amundsen A.H., Fyhri A., Solberg S., Road traffic noise – the relationship between noise exposure and noise annoyance in Norway, *Applied Acoustics*, 65, 9, 2004, pp.803-912

[13] Lakusic S., Dragcevic V., Rukavina T., The effect of tram track permanent way closure system on the level of noise, *Urban Transport and the Environment in the 21st Century*, WIT Press, 2003

[14] *** Städtebauliche Lärmfibel. Hinweise für die Bauleitplanung, Baden Würtemberg Innenministerium, 1991

[15] *** Lärmbekämfung in Wien. Enwicklung. Stand Tendenzen. Magistratsabteilung 22 Umweltschutz