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Evaluation models for the noise diminution due to the phonique barrier walls

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The paper contains our study regarding the reduction of urban noise using the sonic barrier walls as to the EMPARA procedure, which is based on the simplified standard method for measurements and computing of surface traffic noise inside urban agglomeration, as they are given in SRM2 laws (Netherlands standards). The studies are made taking into account all parameters that characterize the noise attenuation. The graphical representations are made considering "n-1" constant parameters, and one parameter varying with time. In this way we obtained the influence of each parameter in the diminution of the urban noise using the noise barrier walls. In addition we realized a measurement for a real barrier wall inside the city of Oradea. Our study also contains a FEM model for the analyzed configuration. The comparison between measurements and computation was fair enough, which means that our theoretical study is acceptable and characterizes the noise pollution and its diminution in the urban agglomeration. The measurement-device was a CENTER 322 Sound Lever Meter.

1 Introduction

As the every day urban traffic pollution through noises emission become an important problem, studies in more and more detailed forms appeared, in connection with sounds propagation and possibilities for attenuation of noises generated by automobiles.

Experimental researches and noises measurements are completed with analysis methods elaboration which, are capable to generate noise levels prediction, noise propagation and to help in noise reduction efficient facilities designing.

Achieved studies are oriented in principal on analyzing different noise sources as vehicles motorization and wheels rolling on the carriage road and different methods of absorbing noises.

As study methods are used:

- Boundary Element Method – BEM;
- Finite Element Method – FEM;
- Algorithmic Methods;
- Finite Volumes Method.

Most used methods in acoustic analysis field are BEM, FEM and all methods based on numerical solving of partial derivatives equations that describe resonance phenomena (eigen-frequencies analysis) and sound wave propagation phenomena.

In this paper Finite Element Method was used, applied with MATLAB® software.

2 Eigen-frequencies analysis

Eigen-frequencies analyze of 3D space distributed objects is very important for resonant phenomena study. For some frequencies of the sound waves, walls vibrations or buildings windows. Generally speaking this phenomenon appears at low-frequencies domain where amplitudes maximum are well defined. The phenomenon is less frequent in medium and high frequencies domain.

Each eigen-frequency is connected to an eigen-mode of vibration. Study of eigen-modes helps to constructive optimization of structures of buildings and of the absorbing elements.

Free air propagation of sound is described in wave propagation differential equation:

$$-\Delta p + \frac{1\partial^2 p}{c^2 \partial t^2} = 0 \qquad (1)$$

in which *p* is pressure, and *c* is sound speed. If air layers medium is in motion by a source that harmonically oscillates (which can be materialized for example by a vehicle motor) a sound wave with the principal frequency is generated. A harmonic solution of the following form is searched:

$$p = Pe^{i.2.\pi.f.t} \qquad (2)$$

Thus wave equation may be written in simplified Helmholtz equation in which P is the amplitude of acoustic disturbances

$$\Delta P + k^2 P = 0 \qquad k = \frac{2\pi f}{c} \qquad (3)$$

If we consider perfect rigid frontiers, based on linearized hydrodynamics equations it may be written the following relation:

$$\nabla p = -\rho \frac{\partial u}{\partial t} \qquad (4)$$

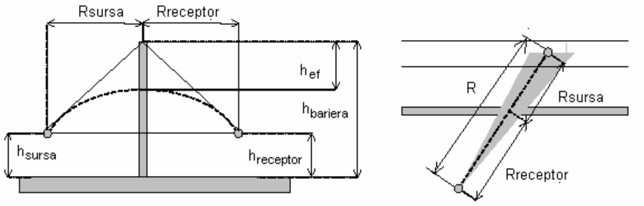
In this relation ρ is density, and u is speed. Thus frontier conditions are Neumann type: $\overline{n}\nabla p$.

This analyzing method may be applied in phonic barriers design, buildings placement thus to obtain a good sound and noise attenuation which is propagated in medium.

Method was implemented in MATLAB® software and may be applied in sound propagation in different media problems study.

3 Evaluation model in sound pollution attenuation. Attenuation due to phonic barrier

Attenuation due to phonic barrier, as EMPARA procedure, is based on simplified standard method for measuring and calculation of street noise, as it is described in Dutch laws, SRM2. Parameters which determine barrier attenuation are height of the barrier and distances between road segment and barrier respective between barrier and receptor – for a certain barrier locals. (As EMPARA says, street is divided in small segments and it is calculated in succession their contribution to the global noise level). Parameters are presented in Figure 1.



,Fig.1 Parameters that determine phonic barrier attenuation.

This determines a curved trajectory of wave transmission, which gives an effective less barrier height denoted by (h_{ef}):

$$h_{ef} = h_{bariera} - \left(h_{sursa} + \left(h_{receptor} - h_{sursa}\right)\cdot\frac{R_{sursa}}{R} + \frac{R_{receptor}\cdot R_{sursa}}{16R} \right) \quad (5)$$

For effective barrier height, difference of acoustic path *z*, is calculating as follows:

$$z = \frac{h_{ef}\left|h_{ef}\right|}{2}\left(\frac{1}{R_{sursa}} + \frac{1}{R_{receptor}}\right) \quad (6)$$

The attenuation due to phonic barrier is defined as:

$$A_{bariera} = G\left(\frac{2f_{ef}\cdot z}{c}\right) - C_{profil} \quad (7)$$

C_{profil} is considered 2dB (A) for mud walls and zero for different barriers. Function is given by:

$$G\left(\frac{2f_{ef}\cdot z}{c}\right) = G(N) = \begin{cases} 10.\log(3+19.N)\ \sim, N \ge 0 \\ 10.\log(3.e^{10.N})\ \sim, N < 0 \end{cases} \quad (8)$$

Where c is the speed of sound (341 m/s) and f_{ef} is the effective frequency for barrier attenuation. This decrease with increasing distance to receptor and it is given by:

$$f_{ef}(R) = \frac{f_0}{1 + 5.10^{-4}R} \quad (9)$$

Equation (8) results on the fact that barrier attenuation decrease due to air absorption at large distances increasing. For road traffic noise frequency f_0 is about 800 Hz.

Using relation (6) one may represent attenuation variation in relation with different constant parameters (Fig. 2 and Fig. 3)

Notes:

1. As it is given in ISO 10847, measurements are averaged in variable time, A-weighted with the noise levels conditioned before wind. For determining barrier attenuation, a set of measurements is made for each location. Noise level is measured for a referenced position of 1m above the barrier, simultaneously with each set of measurements. Noise level in the reception point in the absence of barrier is calculated on the reference value as in the spectrum model (SRM2), used in Dutch laws of noise. Barrier attenuation results from relation:

$$A_{barrier} = \left(L_{ref} - A_{SRM2}\right) - L_{Aeq,measured} \quad (10)$$

The term in parentheses is a level calculated in absence of barrier (predicted „PRIMARY level" in ISO 10847). ASRM2, determined by VROM, is the attenuation excess (including ground effects and air absorption) with regard of the reference position of the receptor, in barrier absence.

2. In calculus software programs, used variables are:

A_b – Barrier attenuation ($A_{barrier}$=$A_{bariera}$);

h_b – Barrier height ($h_{bariera}$);

h_s – Source height (h_{sursa});

h_r – Receptor height ($h_{receptor}$);

R_s – Distance from source to barrier (R_{sursa});

R_r – Distance from receptor to barrier ($R_{receptor}$).

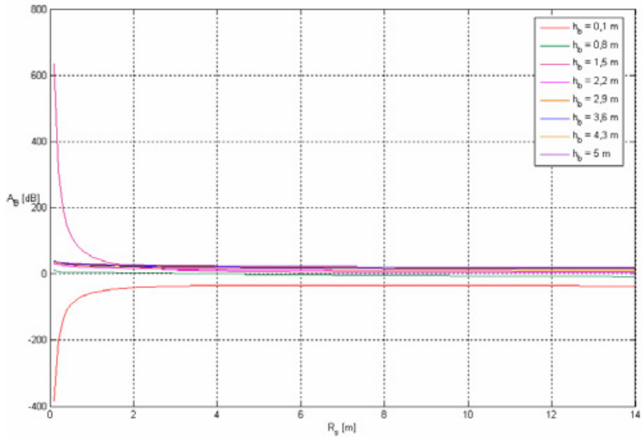


Fig.2 Barrier attenuation variation with constant parameters $h_s = 0{,}7$ m; $h_r = 1{,}7$ m; $R_r = 10$ m; $C_p = 0$ dB.

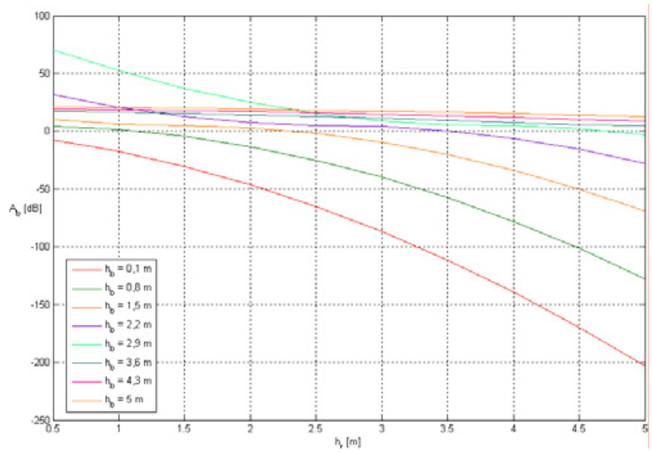


Fig.3 Barrier attenuation variation with constant parameters $h_s = 0{,}7$ m; $R_s = 14$ m; $R_r = 10$ m; $C_p = 0$ dB.

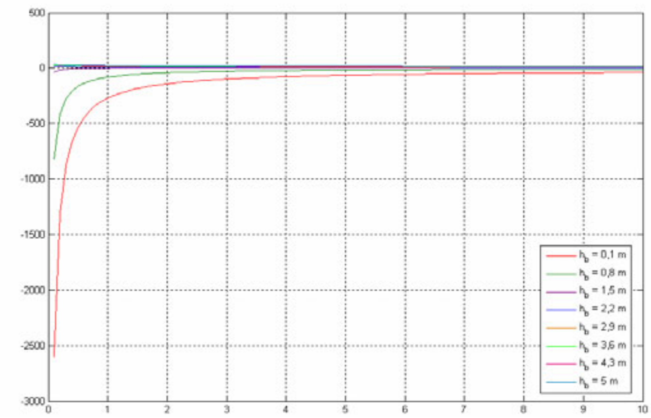


Fig.4 Barrier attenuation variation with constant parameters $h_s = 0{,}7$ m; $R_s = 14$ m; $R_r = 10$ m; $C_p = 2$ dB.

In figures 2, 3 and 4 the parameters give values, but they are informative for drawing as complete as possible of the family of variation curves for barrier attenuation, in order to surprise all the possible aspects of their variation.

4 Case study. Determining phonic attenuation in zone „Sosea de centura" of Oradea municipality

4.1 Presentation of the zone that is discussed in the case study

Fig. 5 Zone where measurements were performed-photo.

Measurements for determining phonic attenuation were made in a residential zone close to marginal road of Oradea municipality (Fig. 5).

Details of the interest zone at the measuring point are presented in figure 6.

Fig. 6 Measurements zone – map (red point).

Calculus schematics of attenuation of the phonic barrier, adapted to case studied, are presented in Figure 6.

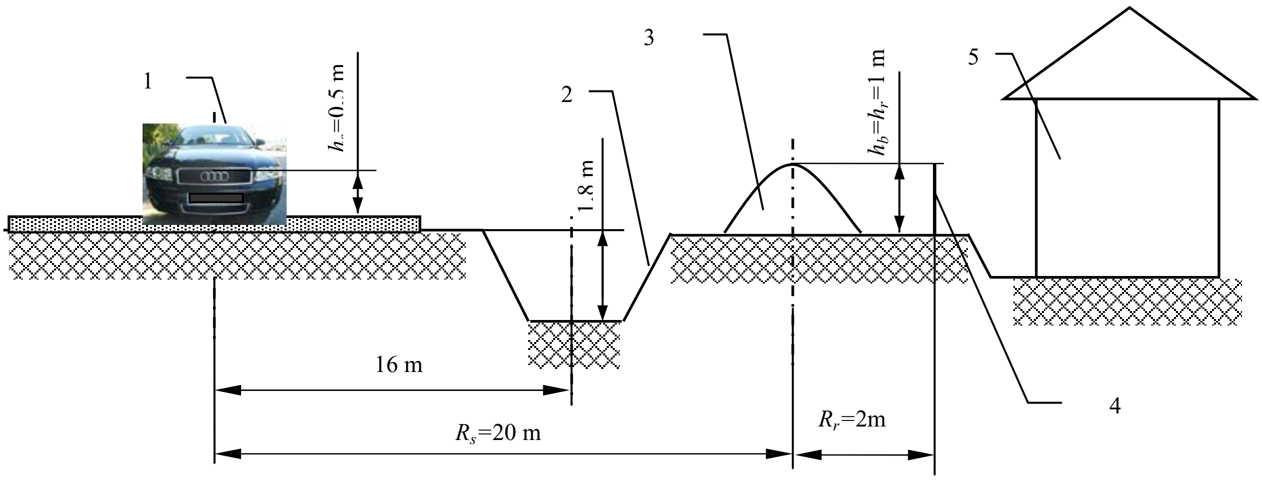


Fig. 7 Calculus schematics of barrier attenuation. Case study
1- source; 2- ditch, 3- earth wall (barrier), 4- receptor, 5-housesMeasurements zone – map (red point).

4.2 Analytical determination of phonic attenuation

For case in study, given in the following, relevance is only for those curves that are reflecting a variation in positive domain of the attenuation variable with values in formula (9) in which terms that are included are conditioning this fact.

Case study: Earth barrier with h_b=1m; Cp=2dB and R_s= 20 m; R_r=2m; h_s=0, 5 m; h_r=1m. It is observing that at a distance of 2m from the barrier attenuation is about 5, 2 dB (Fig. 8).

If the noise source modifies its position in the area situated between 14 m and 20 m, situation is presented in the figure 9. The barrier produces the good attenuation in each situation if the measurements are made at the 2m distance.

In order to verify this situation decibels level measurements were made both at the source and behind the barrier, at 2 m distance.

Measurements were performed in two moments of the day: - 09:15 am and 08:00 pm. Noise level was also measured both at the source and at the receptor.

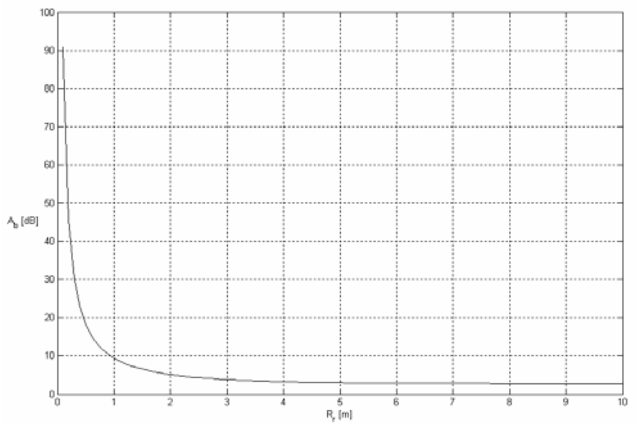


Fig. 8 Barrier attenuation with the source situated at the constant distance $R_S = 20$ m; $h_S = 0{,}5$ m; $h_r = 1$ m.

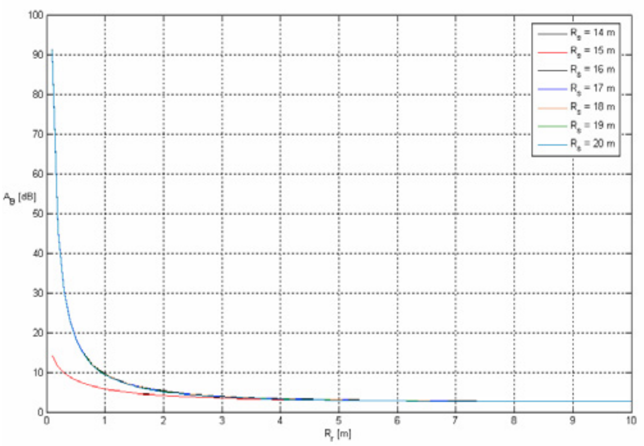


Fig. 9 Barrier attenuation with the source situated at the variable distance $R_S \in [14;20]$ m; $h_S = 0{,}5$ m; $h_r = 0.7$ m.

4.3 Finite element method study of phonic attenuation

Analytical study of phonic pollution attenuation for a zone of Europe residential area in Oradea municipality was achieved helped by EMPARA model in the previous chapter. A FEM model was produced for the same situation zone. Model is assuming that a source of noise at 30 m distance from the buildings of the area at the marginal road of the municipality exists (model dimensions are the same as in figure 6).

Model geometry is presented in figure 10 and finite element mesh is presented in the figure 11. The mesh is defined by 4744 nodes and 9152 triangular elements

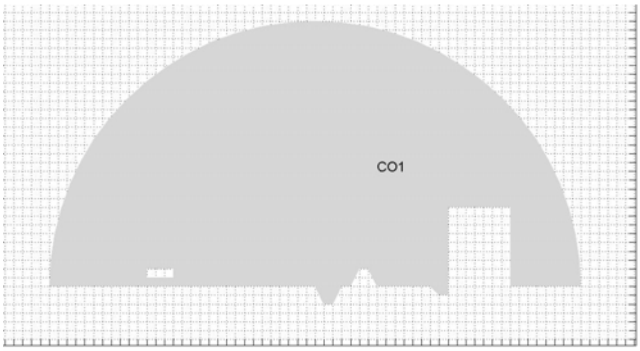


Fig. 10 Model geometry of the road transversal section.

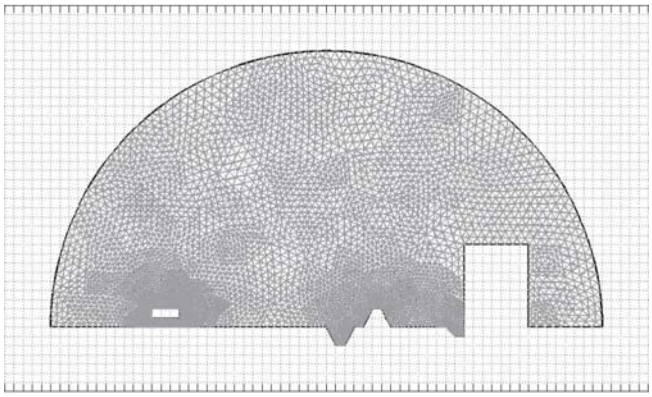


Fig.11 Finite elements mesh.

Study was performed for several excitation frequencies of the source (25, 35, 45, 55 and 65 Hz)

In this model c represents speed of sound, ρ is density of air, k is number of wave, d describes deformation amplitude and n is a normal unit vector at the surface of the source oriented to exterior. Sound pressure is given by Helmholtz equation (3). In order to model pressure wave excitation onto solid frontier (source) we may put Neumann condition:

$$\frac{\partial p}{\partial n} = -\rho \frac{\partial u_n}{\partial t} \qquad (11)$$

Where u_n is the normal component of speed. In this case:

$$\frac{\partial p}{\partial n} = -\rho d 4 \omega^2 e^{2i\Phi} \qquad (12)$$

Where Φ is the phase-shift. If we assume that no incident sound waves exist, generated field satisfies Sommerfeld radiation condition.

Exterior frontier (semi-circular form) condition is such chosen that permits wave passing with no reflection (totally absorption). As source overlie tends to infinity sound pressure satisfies one direction wave equation:

$$\frac{\partial p}{\partial n} + c\xi \nabla p = 0 \qquad (13)$$

This equation permits wave motion into positive direction ξ (ξ is radius distance to source). In order to simplify it is considered that exterior normal of the calculus domain is approximated with exterior direction ξ. Considering harmonic solution in relation with time, eq. (4) becomes generalized Neumann frontier condition:

$$\frac{\partial p}{\partial n} = -kip \qquad (14)$$

In sound waves modeling is important number of nodes on a wavelength choosing to be less then 4.

For reflectant walls is choose a Neumann frontier condition given by:

$$\frac{\partial p}{\partial n} = 0 \qquad (15)$$

Simulation results are presented for different frequencies of the source in the form of contour line of sound pressure in figure 12 and under the form of the field intensity in figure 13 for a frequency of 65 Hz.

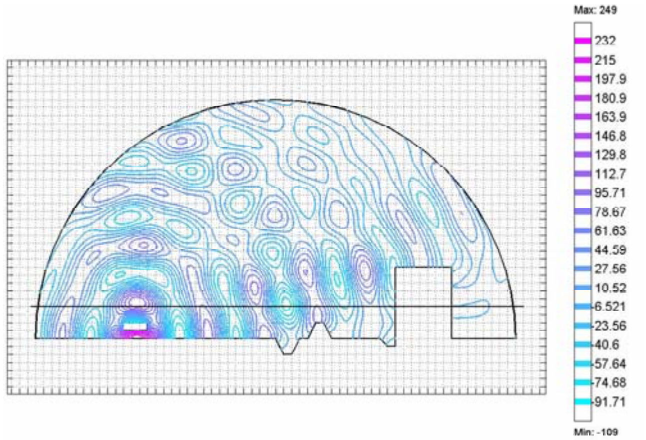


Fig. 12 Sound waves propagation for a source frequency of f = 25 Hz (contour plot).

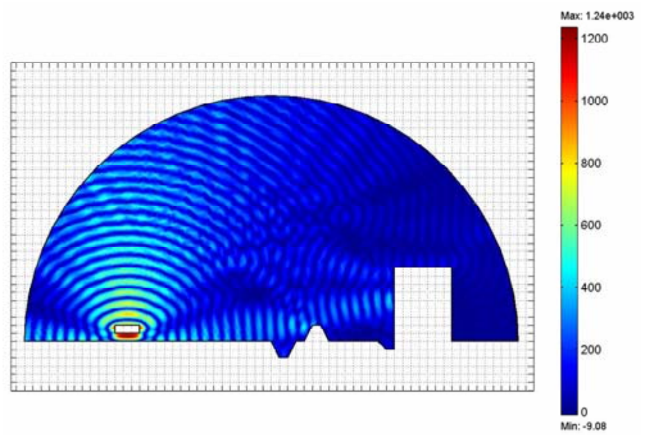


Fig. 13 Sound waves propagation for a source frequency of f = 65 Hz (field intensity display).

5 Conclusions

Starting from presented diagrams one may study influences of shielding elements have on noise transmitted to buildings in the modeled medium. Models presented are susceptible for improving by defining some higher resolution mesh of elements, but this needs higher performances computers with improved memory capacities, especially for 3D simulations. Experimental and other analysis methods validation of the results are also needed.

Mathematical model used for sound pollution attenuation may be used for phonic barrier design, in order to satisfy standards of permitted noise level in residential areas. This can become a working instrument for authorities in the field.

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