EMPARA ATTENUATION AND FEM PROPAGATION MODELS FOR SOUND AND NOISE REDUCTION – A STUDY CASE

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Keywords: *phonic barrier, EMPARA attenuation model, FEM propagation model*

Abstract: The paper contains our study regarding the reduction of urban noise using the phonic barrier walls as to the EMPARA (*Environmental Model for Population Annoyance and Risk Analysis*) model, 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 noise attenuation for a real barrier wall inside the city of Oradea. Study also contains a FEM model for the analyzed configuration. Comparison between measurements and computation was fair enough. 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 (Helmholtz type):

$$-\Delta p + \frac{l\partial^2 p}{c^2 \partial t^2} = 0 \tag{1}$$

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:

$$p = \hat{p}e^{i.2.\pi.f.t} \tag{2}$$

Thus wave equation may be written in simplifyed Helmholtz equation in which $\hat{p}$ is the amplitude of acoustic disturbunces:

$$\Delta\hat{p} + k^2\hat{p} = 0 \quad \text{with} \quad k = \frac{2\pi f}{c} \tag{3}$$

in which f is sound frequency.

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

$$\nabla p = -\rho\frac{\partial u}{\partial t} \tag{4}$$

in which ρ is density, and u is speed of wavefront. Frontier conditions are Neumann type: $\bar{n}.\nabla p = 0$. This analyzing method may be applied in phonic barriers design, buildings placement thus to obtain a good sound and noise atenuation which is propagated in medium.

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

3. EMPARA MODEL IN SOUND POLLUTION ATTENUATION. PHONIC BARRIER

Attenuation due to phonic barrier, as EMPARA model, 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 *hight of the barrier* and distances between road segment and barrier respective between barrier and receptor – for a certain barrier locals. (As in EMPARA, street is divided in small segments and it is calculated in succesion their contribution to the global noise level). Paramaters are presented in Figure 1.

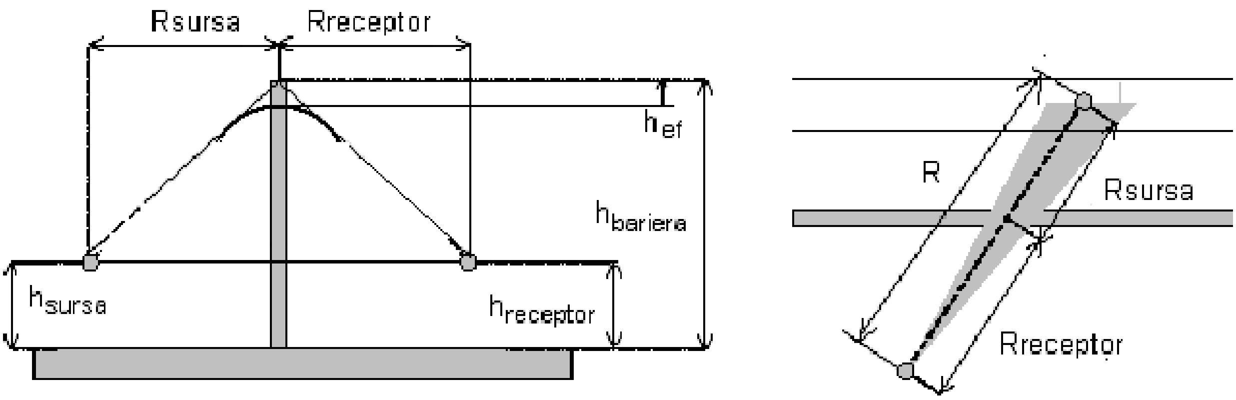

Fig. 1. Parameters characterizing phonic barrier attenuation

The effective barrier hight is the geometric hight of the barrier within a correction given for meteorological conditions as: before wind. This determines appereance of a „curved" trajectory of wave transmission, which gives an effective less barrier hight denoted by (h_{ef}):

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

For effective barrier hight, difference af acoustic path z, is calculating as follows:

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

and attenuation due to phonic barrier is defined as:

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

C_{profil} is considered $2\,\mathrm{dBA}$ for mud walls and zero for other different barriers. Function $G(N)$ is given by:

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

where c is the speed of sound in air (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:

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

Equation (8) results on the fact that barrier attenuation decrease due to air absorbtion 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 parameteres (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 madae for each location. Noise level is measured for a referenced position of 1m above the barrier, simultanously 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 $A_{bariera}$ results from relation:

$$A_{bariera} = \left(L_{ref} - A_{SRM\,2}\right) - L_{Aeq,masurat} \tag{10}$$

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

2. In software programs, variables are:

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

h_b – Barrier hight *(* $h_{bariera}$ *);*

h_S – Source hight *(* h_{sursa} *);*

h_r – Receptor hight *(* $h_{receptor}$ *);*

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

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

In Figures 2, and 3 parameters given values are informative for drawing as complete as possible of the family of variation curves for barrier attenuation, in order to surprize all the possible aspects of their variation.

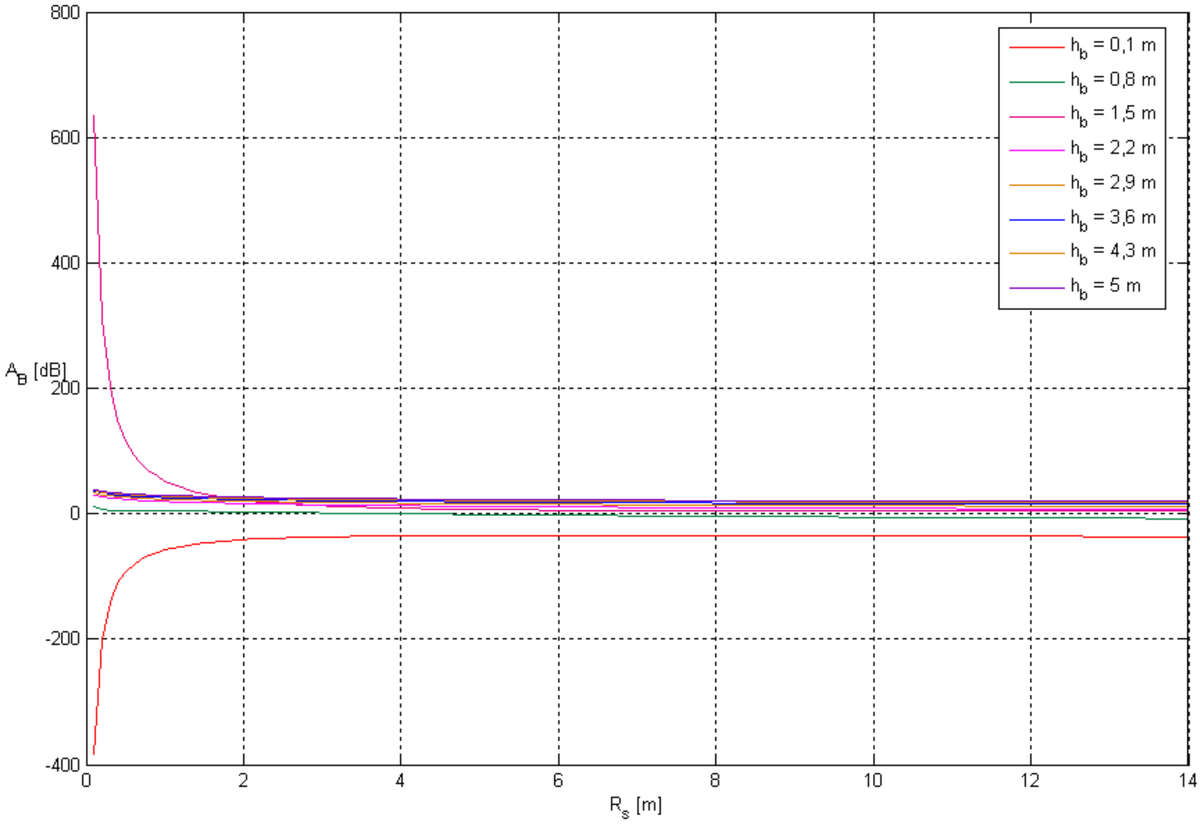

Fig. 2. Barrier attenuation variation $A_b = A_b(R_s)$***. Constant parameters:***

$h_s = 0{,}7\,\text{m}; h_r = 1{,}7\,\text{m}; R_r = 10\,\text{m}; C_p = 0\,\text{dB};$

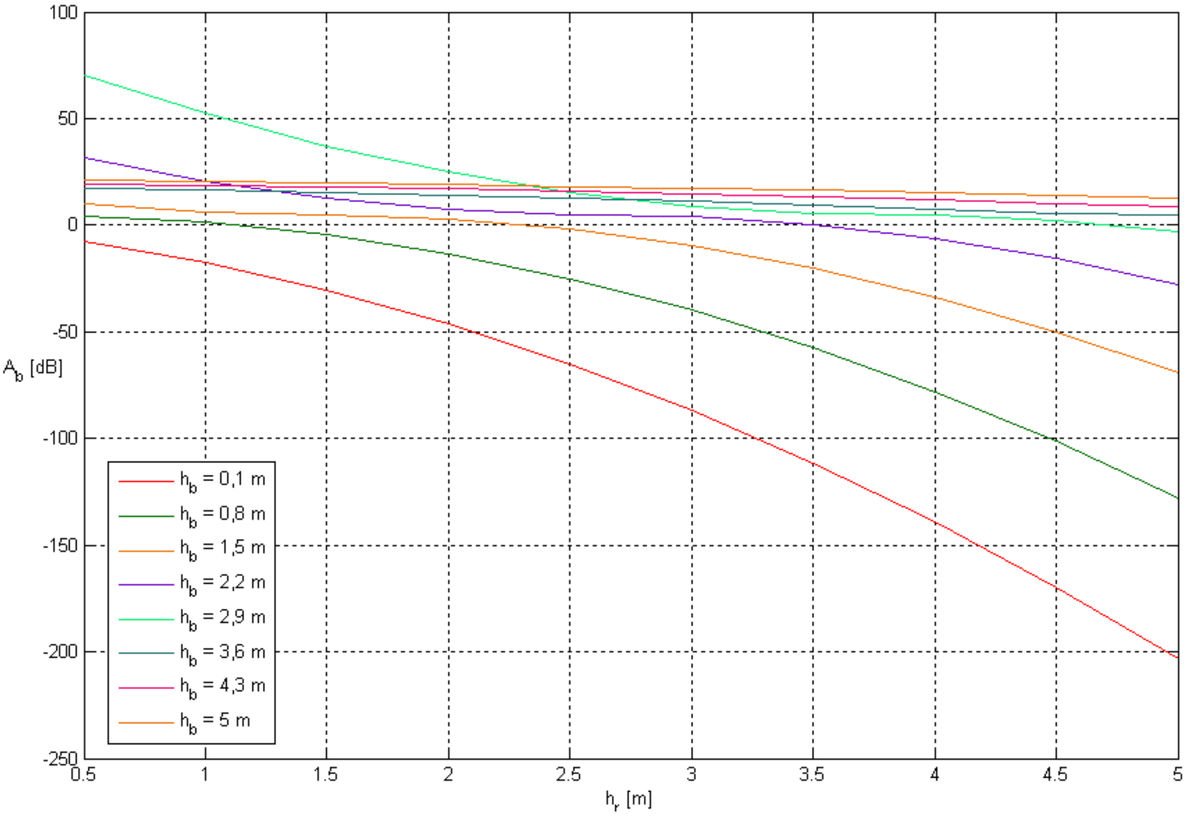

Fig. 3. Barrier attenuation variation $A_b = A_b(h_r)$***. Constant parameters:***

$h_s = 0{,}7\,\text{m}; R_s = 14\,\text{m}; R_r = 10\,\text{m}; C_p = 0\,\text{dB};$

4. CASE STUDY.
DETERMINING PHONIC ATTENUATION IN ZONE CITY LIMITS ROAD OF ORADEA

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

Measurements for determining phonic attenuation were made in a residential zone close to city limits road of Oradea. (Figure 4)

Figure 4. Zone where measurements were performed

Figure 5. Measurements zone – map (red point)

Details of the interest zone at the measuring point are presented in Figure 5. Calculus schematics of attenuation of the phonic barrier, adapted to case studied, are presented in Figure 6.

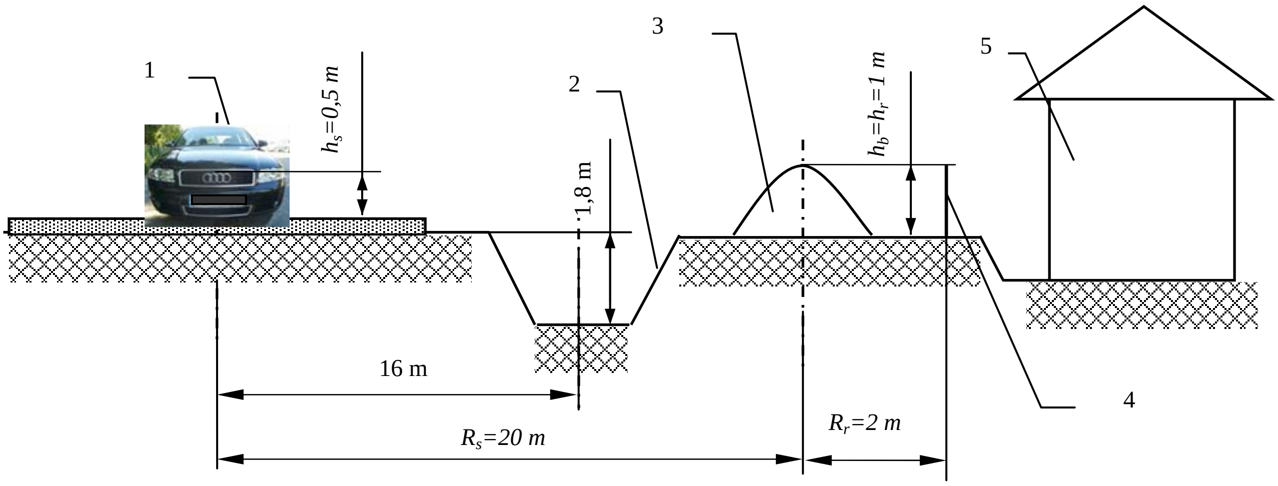

Fig. 6. Calculus schematics of barrier attenuation. Case study.
1- source; 2- ditch, 3- earth wall (barrier), 4- receptor, 5-houses

4.2. Analytical determination of phonic attenuation

For case in study, given in the following, a 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 $h_b = 1\,\text{m}; C_p = 2\,\text{dB}$ şi $R_s = 20\,\text{m}; R_r = 2\,\text{m}; h_s = 0{,}5\,\text{m};\; h_r = 1\text{m}$

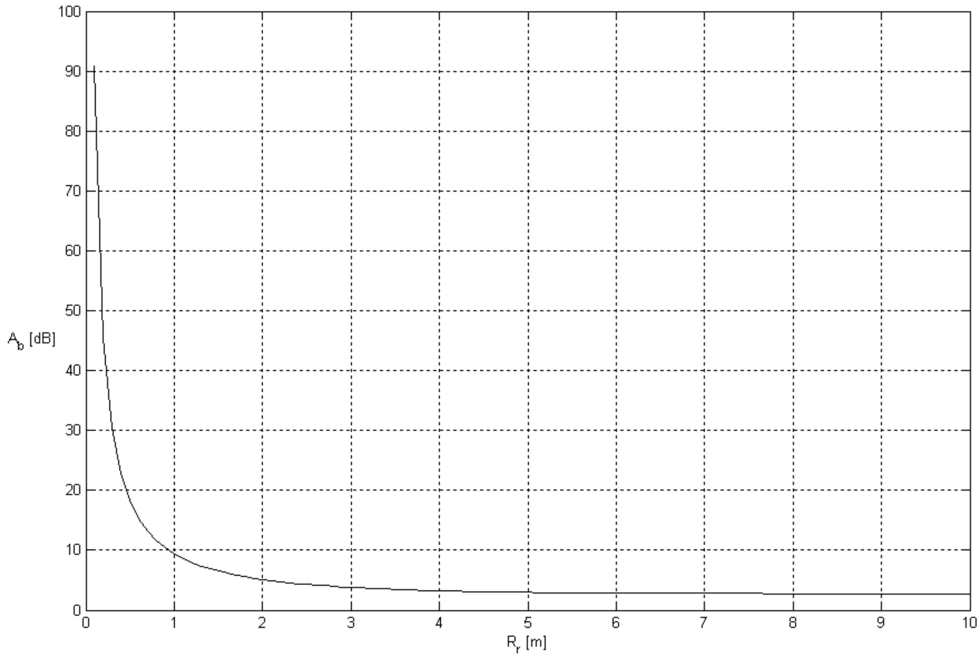

Fig. 7. Earth barrier attenuation for a distance to source taken as a constant
$R_s = 20\,\text{m}; h_s = 0{,}5\,\text{m};\ h_r = 1\,\text{m}$

It is observing that at a distance of *2* m from the barrier attenuation is about 5,2 dB (Figures 7 and 8). 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. Results of measurements are presented in Figure 9 and Figure 10.

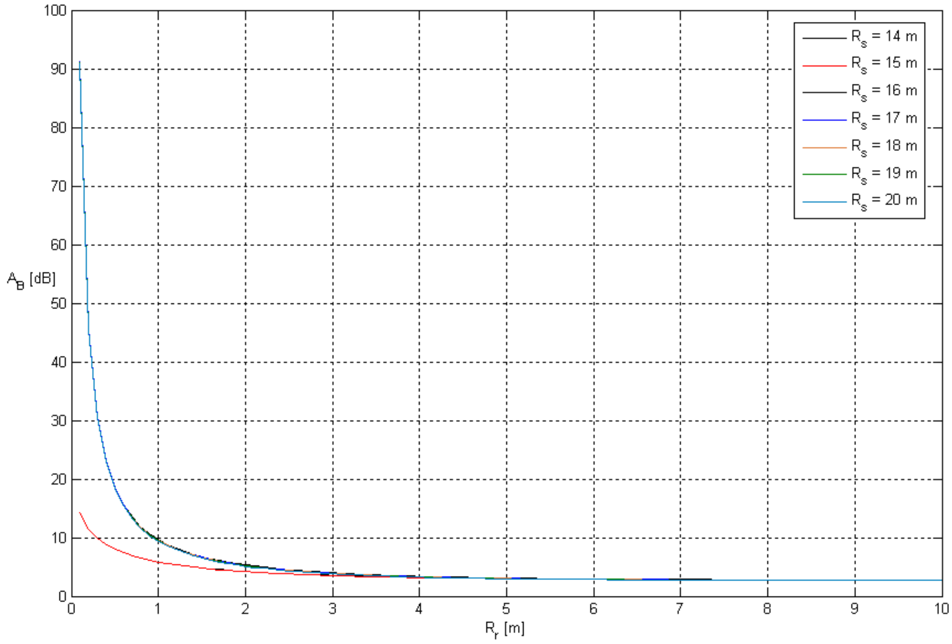

Fig. 8. Earth barrier attenuation for a distance to source taken as variable
$R_s \in [14{,}20]\,\text{m};\ h_s = 0{,}5\,\text{m};\ h_r = 0{,}7\,\text{m}$

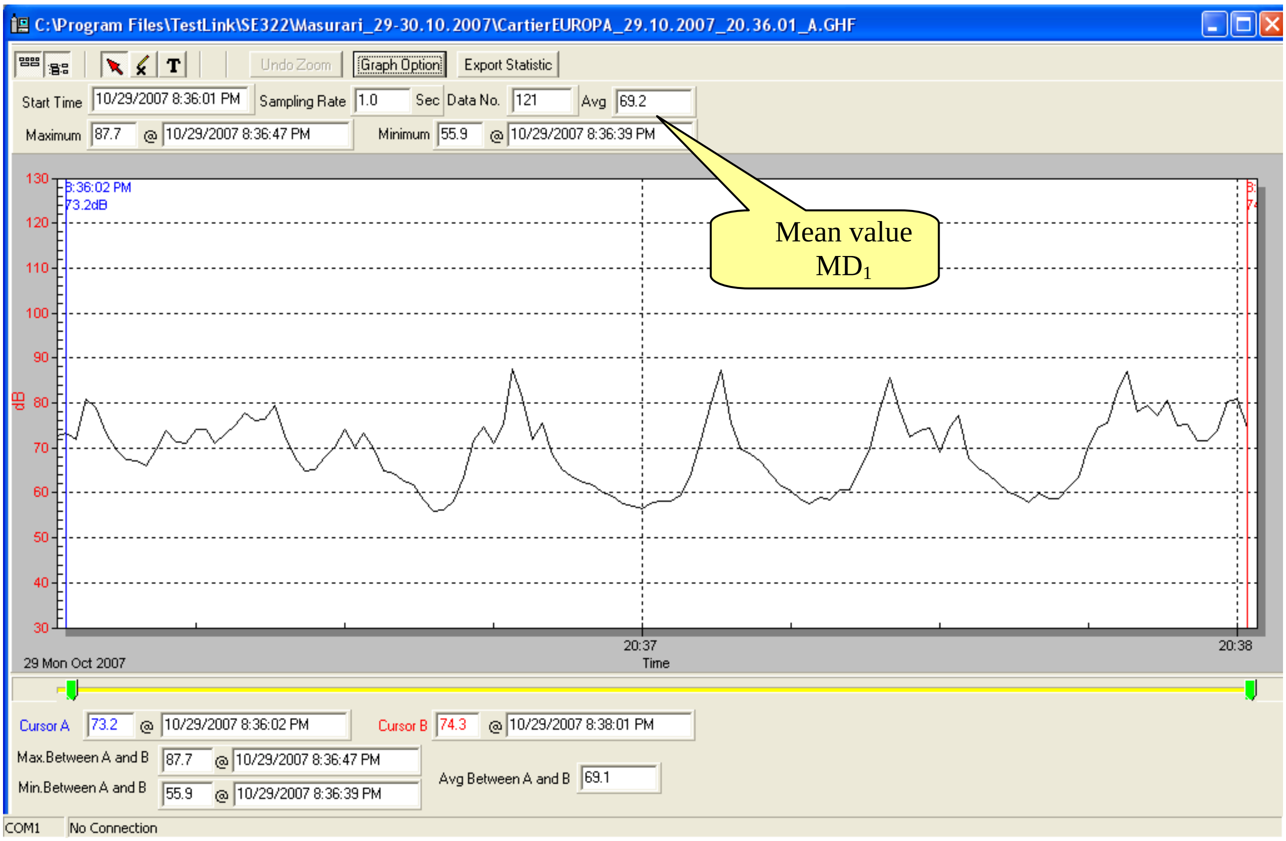

Fig. 9. Measurement results 08:00 PM - at source

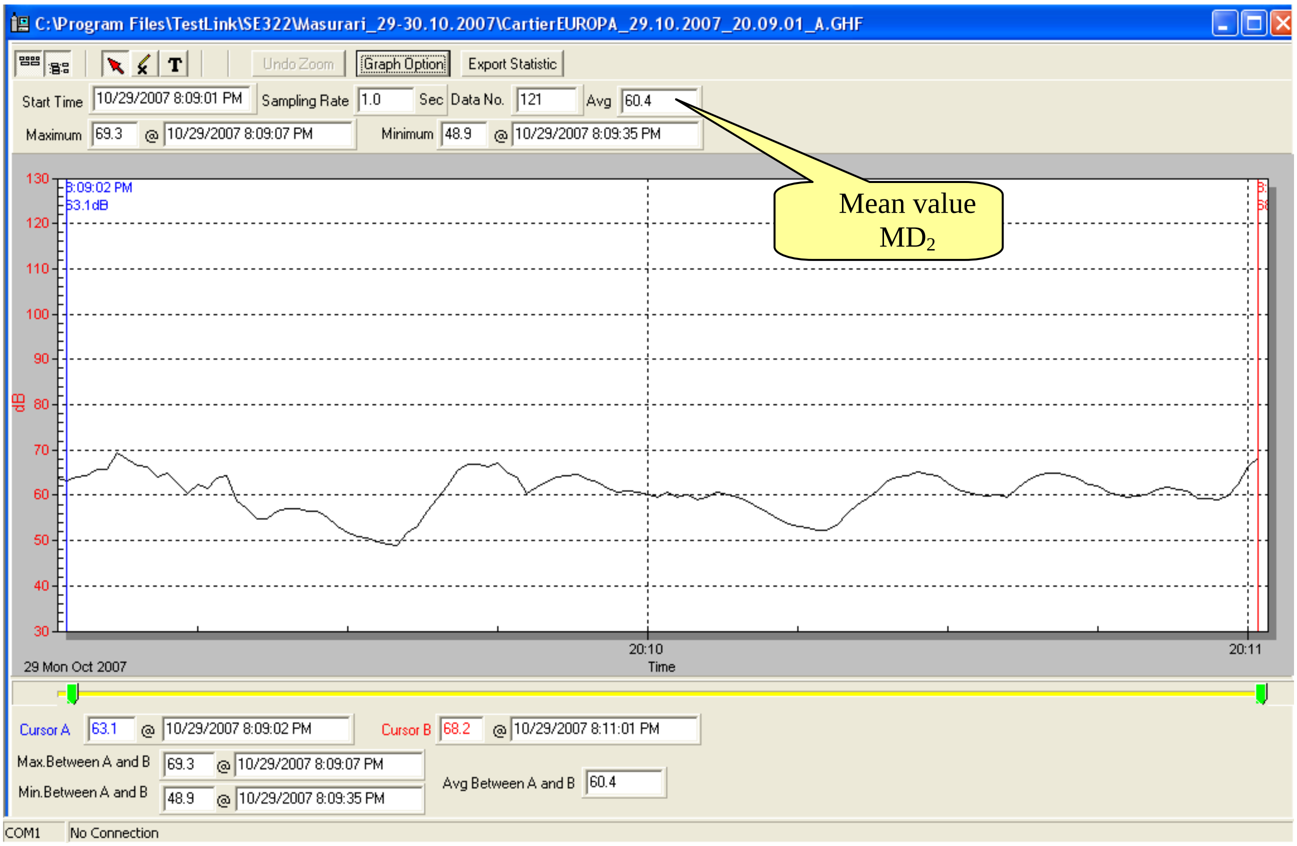

Fig. 10. Measurement results 08:00 PM - at receptor

4.3. A FEM Model

Analytical study of phonic pollution attenuation for a zone of *Europa* residential area in Oradea municipium 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 municipium exists (model dimensions are the same as in figure 6).

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

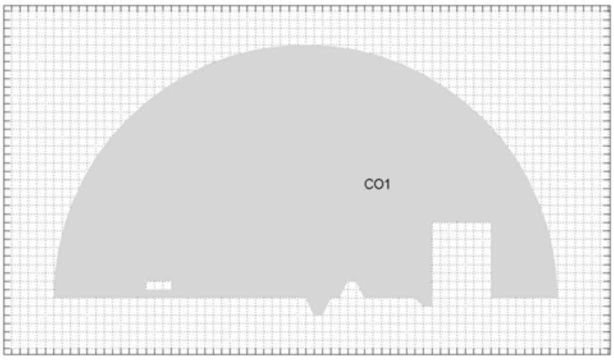

Fig. 11. Model geometry

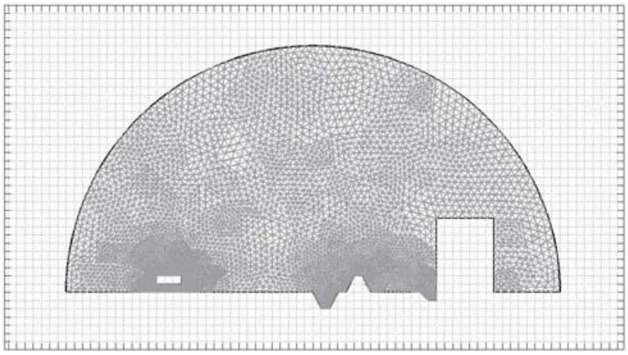

Fig. 12. Finite elements mesh

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

In this model a 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:

$$\frac{\partial p}{\partial n} = -\rho \frac{\partial u_n}{\partial t} \tag{11}$$

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

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

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

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

$$\frac{\partial p}{\partial n} + c\xi\nabla p = 0 \tag{13}$$

which 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:

$$\frac{\partial p}{\partial n} = -kip \tag{14}$$

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

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

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

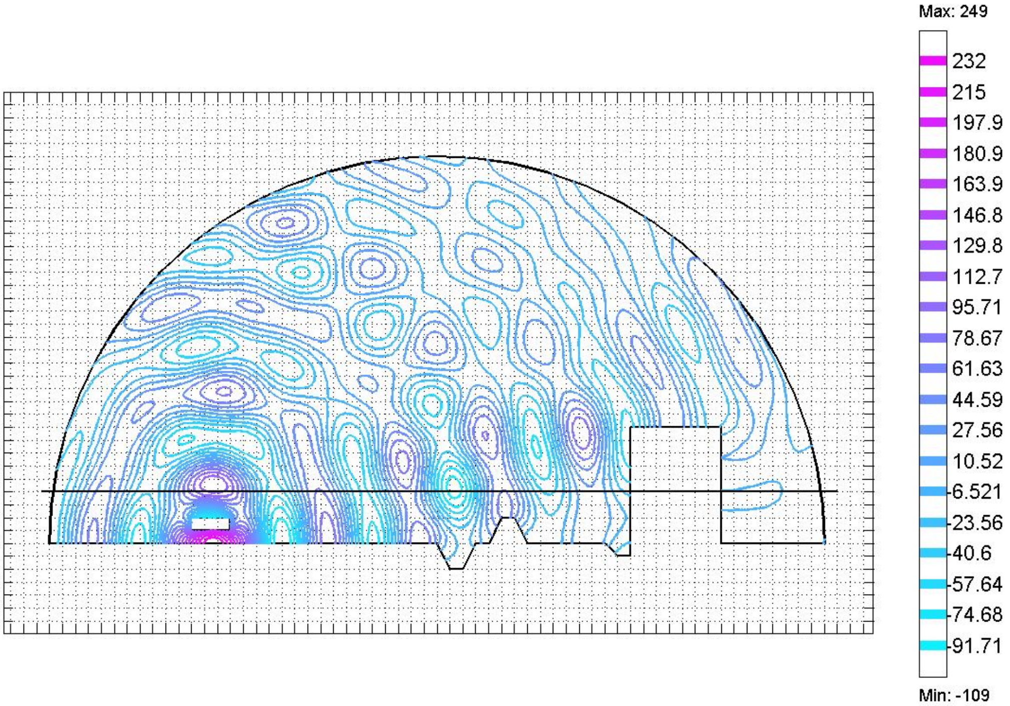

Fig. 13. Sound waves propagation for a source frequency of f = 25 Hz (contour plot).

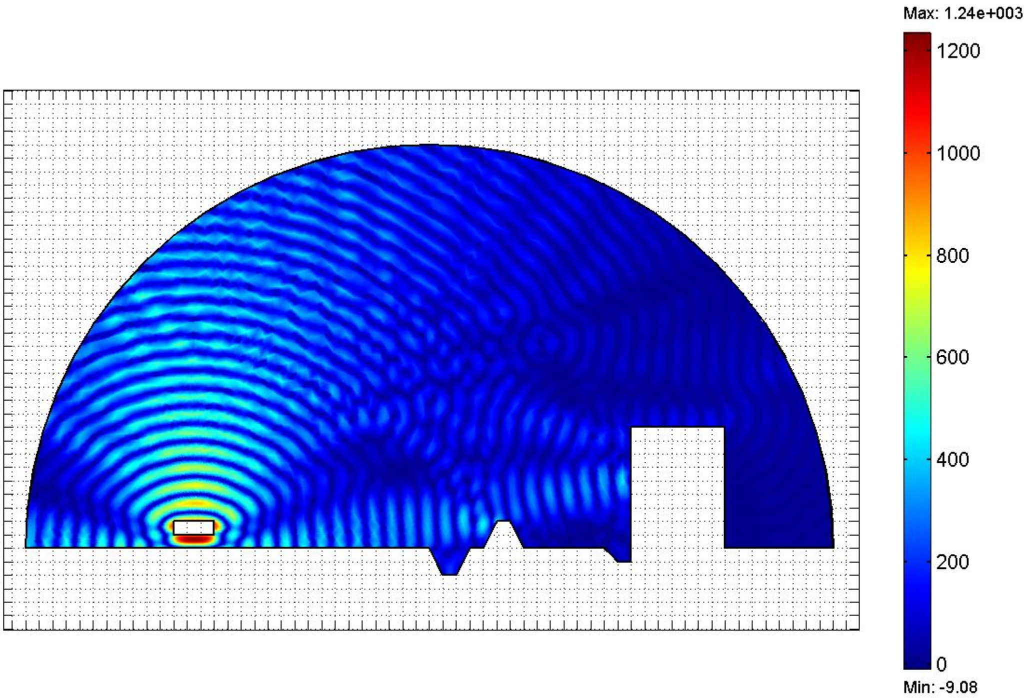

Fig. 14. Sound waves propagation for a source frequency of f = 65 Hz (field intensity display)

Simulation results are presented for different frequencies of the source in the form of contour line of sound pressure in Figure 13 and under the form of the field intensity in Figure 14 for a frequency of 65 Hz.

5. CONCLUSIONS

Starting from presented diagrams one may study influences of shielding elements have on noise transmitted to buildings in the modelled 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, specialy 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.

ACKNOWLEDGEMENT. The authors acknowledge the support of the Projects CEEX 129/2006 and 751/2006.

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