DESIGN OF THE SOUND ABSORPTION COEFFICIENT OF THE NOISE BARRIER SURFACE

[a] JAN ŠLECHTA

The Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7, 166 29 Praha 6
email: [a] jan.slechta@fsv.cvut.cz

This work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS13/111/OHK1/2T/11.

Abstract: The purpose of this paper is to verify whether the image sources method used for the calculation of the sound wave reflected from a vertical obstacle is precise enough to be used in noise mapping. Numerical modelling with the boundary element method was used as a tool for the verification of the method precision. The insertion loss of the obstacle was calculated with the BEM in many receivers. Two variants of sound absorption coefficient of the noise barrier surface were included in the calculation. Results obtained by the BEM calculations were fitted with the quadratic curve and compared with the values obtained by the image sources method. It was concluded that the image sources method is on the safe side. Nevertheless, the deviation on the safe side was acceptable.

Keywords: image sources, boundary element method, insertion loss, noise barrier, absorption coefficient, sound wave reflection.

1 Introduction

When designing a noise barrier the following variables must be specified: dimensions, the sound reduction index and the absorption coefficient of its surface. Accordingly, when calculating the sound pressure level in the receiver a direct sound ray must be taken into account as well as a sound ray reflected from a terrain and vertical obstacles. The absorption coefficient of these obstacles plays an important role in both cases.

Currently, the process of strategic noise mapping is running in the EU member states on the basis of the Directive 2002/49/EC of the European Parliament and of the Council (Ref. 2). In this directive interim methods for the strategic noise mapping were established.

The French method NMPB-Routes-1996 was chosen as recommended interim method for the prediction of the noise caused by road traffic. This method describes the calculation of the sound wave reflection from a vertical obstacle using the image sources method (Ref. 12).

Initially, this interim method was supposed to be replaced by the method Harmonoise, which also uses the image sources for the calculation of the sound wave reflection (Ref. 9). Fresnel zones in the Harmonoise method enable to predict even reflections from surfaces with inconstant absorption coefficients.

The image sources method was also used in the method CNOSSOS-EU, which was eventually chosen for the strategic noise mapping in the EU member countries (Ref. 6).

The image sources method is an engineering method suitable for practical use. Its main disadvantage is that it does not take into account the interference of the direct and reflected sound wave. Contributions from various sources are summed energetically.

In contrast, the boundary element method (the BEM) takes into account the interference of the direct and reflected sound wave (both constructive and destructive). The purpose of this paper is to find out the error caused by using the energetic sum in the image sources method.

2 The Boundary Element Method

The BEM belongs to numerical methods which are used for solving many problems ranging from heat conduction in building constructions to propagation of sound in the outdoor environment. The Matlab implementation 2D OpenBEM (Ref. 5) is very convenient for situations regarding noise barriers.

2D BEM considers a linear coherent source and homogenous conditions of sound propagation, which means that it is impossible to model with the 2D BEM meteorological phenomena like temperature and wind gradients. The partial differential equation, which is valid for pure tones and solved with the BEM, is called the Helmholtz equation (Ref. 8):

$$(\nabla^2 + k^2)\hat{p} = 0 \tag{2.1}$$

Where (Ref. 8):

$$\hat{p} = p(x,y)\mathrm{e}^{-\mathrm{i}\omega t} \tag{2.2}$$

Where ∇^2 is the Laplace operator, k [m^{-1}] is the wave number, $\hat{p}$ [Pa] is the sound pressure expressed by a complex function, p [Pa] is the sound pressure, x and y [m] are the coordinates of a Cartesian coordinate system, e is the Euler number, i is the imaginary number, ω [rad.s^{-1}] is the angular frequency and t [s] is the time.

The BEM can be used merely for cases when a fundamental solution of a partial differential equation is known. The fundamental solution is used as a weighting function in the derivation of the formulas used in the calculation (Ref. 4).

The Green's function is used for the boundary element formulation on the barrier and for the source modelling. It is defined as a solution of a non-homogenous linear differential equation (Ref. 1):

$$(\nabla^2 + k^2)\, G_\beta\, (\mathbf{r},\mathbf{r}_0) = \delta\,(\mathbf{r} - \mathbf{r}_0) \tag{2.3}$$

Where ∇^2 is the Laplace operator, k [m^{-1}] is the wave number, G_β ($\mathbf{r}$, $\mathbf{r}_0$) is the Green's function and δ ($\mathbf{r}$ - $\mathbf{r}_0$) is the Dirac delta function, $\mathbf{r}$ and $\mathbf{r}_0$ are the position vectors of the receiver and the source.

To find a solution of G_β ($\mathbf{r}$, $\mathbf{r}_0$) two boundary conditions are needed. These are: the Sommerfeld radiation condition (for the domains with the infinite extent), which states that energy emitted by the source must be scattered in infinity; and the impedance boundary condition (for the domains with boundaries) which expresses the relation between the particle velocity normal to the boundary with the admittance and the sound pressure (Ref. 8).

3 Image Sources

The image sources are applied in the methods in references 6 and 12 as well as in the standard DS/ISO 9613-2 (Ref. 3), which is the Danish version of the international standard for sound propagation in the outdoor environment.

The image sources are used solely for the calculation of reflections from the obstacles that are declined from the vertical direction less than 15° and with both dimensions bigger than 0.5 m (Ref. 6).

The obstacle (i.e. the noise barrier or the building) is simulated here by an image source. The formula for the calculation of the sound power level of the image source has been described in several methods. Let's quote the new version of French method NMPB 2008 (Ref. 10):

$$L_{w'} = L_w + 10\log_{10}(1 - \alpha_r) \tag{3.1}$$

Where $L_{w'}$ [dB] is the sound power level of the image source, L_w [dB] is the sound power level of the real source, α_r [-] is the absorption coefficient and $0 \leq \alpha_r < 1$.

Fig. 1 shows the situation sketch with the image source.

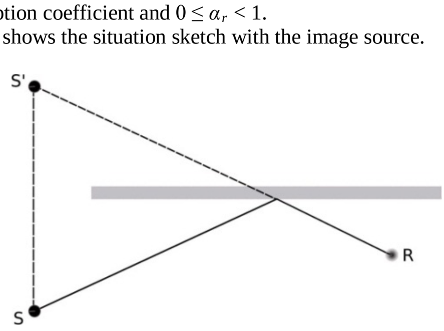

Fig. 1: Reflection from the obstacle calculated using the image sources – S: the source, S´: the image source, R: the receiver (Ref. 10)

Contributions from individual sources are summed energetically in the receiver (Ref. 10):

$$L_{eq,LT} = 10\log_{10}\left(\sum_i 10^{0.1\,L_{i,LT}} + \sum_{i'} 10^{0.1\,L_{i',LT}}\right) \qquad (3.2)$$

Where i are all real sources, $i´$ are all image sources, $L_{i,LT}$ [dB] are the contributions from the real sources, $L_{i´,LT}$ [dB] are the contributions from the image sources and $L_{eq,LT}$ [dB] is the equivalent continuous sound pressure level.

4 Setting of the Calculation

There was modelled a situation which consisted of an obstacle with two variants of the absorption coefficient α [-] (the first variant was the reflective surface: α = 0, the second variant was a rather absorbing surface: α = 0.74).

The 2D OpenBEM software, which was programmed in the Matlab language, does not enable to input the absorption coefficient directly but enables to input the flow resistivity [$N\cdot s\cdot m^{-4}$]. This parameter can be converted to the absorption coefficient for a specific frequency with formulas mentioned in Ref. 7. The terrain was not considered in the model to avoid a distortion by the ground effect. A mono-frequency 500 Hz source was selected.

Two variants of mutual position of the source and the receiver were calculated. The first variant in which the receiver remains in the same position and the source is being moved is depicted in Fig. 2. The second variant in which the receiver is being moved and the source remains in the same position is depicted in Fig. 3.

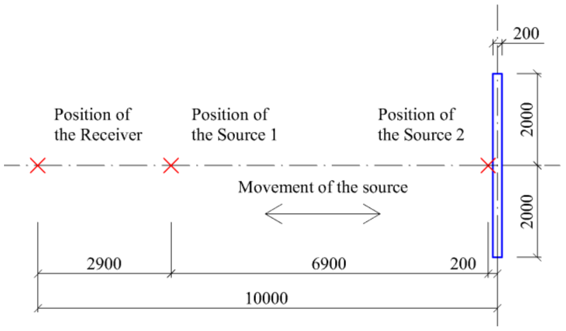

Fig. 2: Geometry of the modelled situation, variant 1

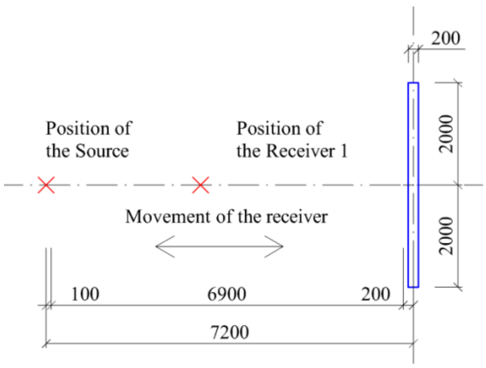

Fig. 3: Geometry of the modelled situation, variant 2

5 Sound Field

The aim of the calculation was to obtain the insertion loss of the noise barrier in the receiver. This receiver was always in the axis of the noise barrier.

The insertion loss is defined as a difference between the sound pressure level in the receiver without considering the noise barrier and the sound pressure level in the receiver with considering the noise barrier.

The term “the insertion loss” is rather confusing in this context. It is usually used to describe the sound field on the other side of the barrier. Its value is usually positive, which means that the noise barrier has reduced the sound pressure level. On the source side of the barrier the value of the insertion loss can be both positive and negative, which indicates the interference between the direct and reflected sound wave.

The sound field in terms of the sound pressure level is showed in Fig. 4 (the source is placed in the position [-5, 0] where zero is the axis of the noise barrier). The insertion loss is showed in Fig. 5.

Fig. 4 and Fig. 5 depict that the standing wave pattern emerges between the noise barrier and the source. In greater distance from the source, the phase difference between the direct and the reflected wave is constant and therefore the insertion loss is also more or less constant.

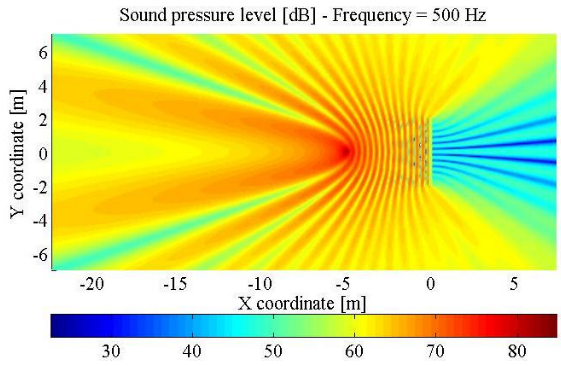

Fig. 4: Sound field – the sound pressure level

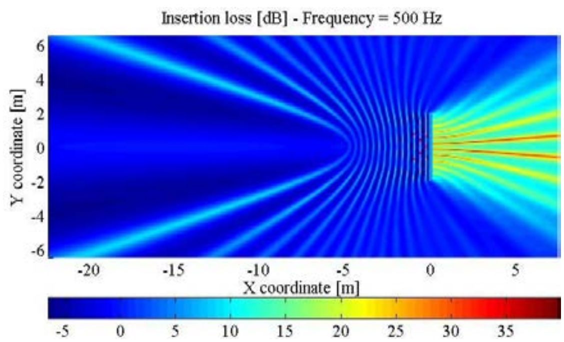

Fig. 5: Sound field – the insertion loss

6 Results of the Calculation

The two variants of the absorption coefficient and mutual position of the source and the receiver resulted in four graphs. The distance of the source or of the receiver from the noise barrier is shown on the x-axis. Using the Matlab tools, the values obtained with the BEM were fitted with a quadratic curve, what made easier to compare the progress of the values calculated using the BEM and NMPB 2008.

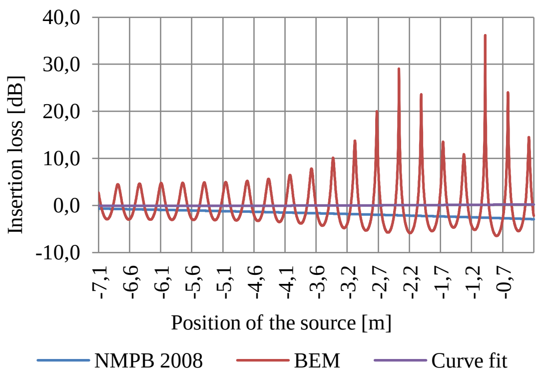

Fig. 6: The insertion loss, variant 1, α = 0

The average value of the insertion loss in Fig. 6 is -1.71 dB (NMPB 2008) and 0.006 dB (the BEM); the difference being 1.71 dB. The correlation between NMPB 2008 and the fitted curve is very high but negative (-0.95).

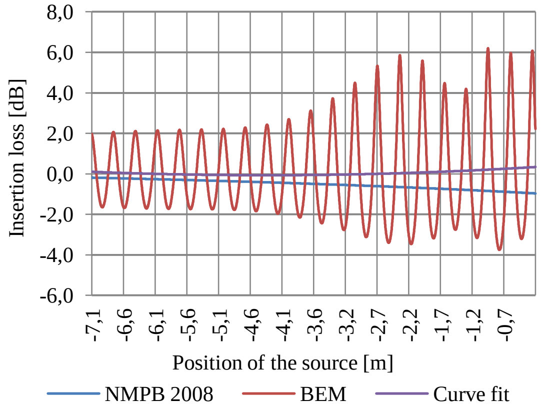

Fig. 7: The insertion loss, variant 1, α = 0.74

The average value of the insertion loss in Fig. 7 is -0.52 dB (NMPB 2008) and 0.035 dB (the BEM); the difference being 0.56 dB. The correlation between NMPB 2008 and the fitted curve is high but negative (-0.72).

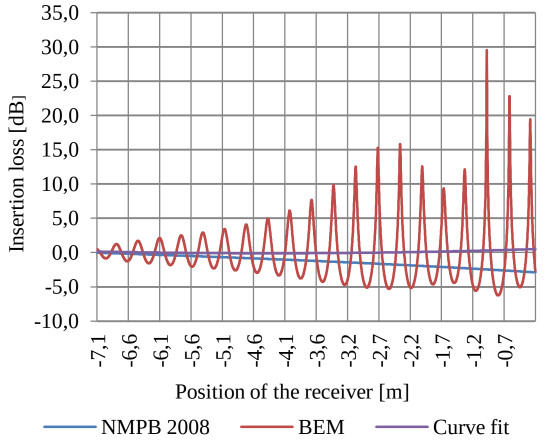

Fig. 8: The insertion loss, variant 2, α = 0

The average value of the insertion loss in Fig. 8 is -1.30 dB (NMPB 2008) and 0.049 dB (the BEM); the difference being 1.35 dB. The correlation between NMPB 2008 and the fitted curve is high but negative (-0.70).

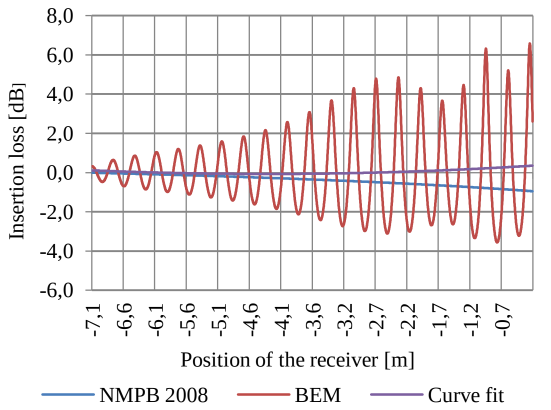

Fig. 9: The insertion loss, variant 2, α = 0.74

The average value of the insertion loss in Fig. 9 is -0.39 dB (NMPB 2008) and 0.038 dB (the BEM); the difference being 0.43 dB. The correlation between NMPB 2008 and the fitted curve is high but negative (-0.72).

7 Comparison of the Absorbing and the Reflecting Noise Barrier

To get an idea about how the absorption coefficient influences the resulting sound pressure level another two graphs are depicted in Fig. 10 and Fig. 11. One can see that the values of the sound pressure level calculated with a lower absorption coefficient are decreasing. This statement is true both for the BEM and NMPB 2008.

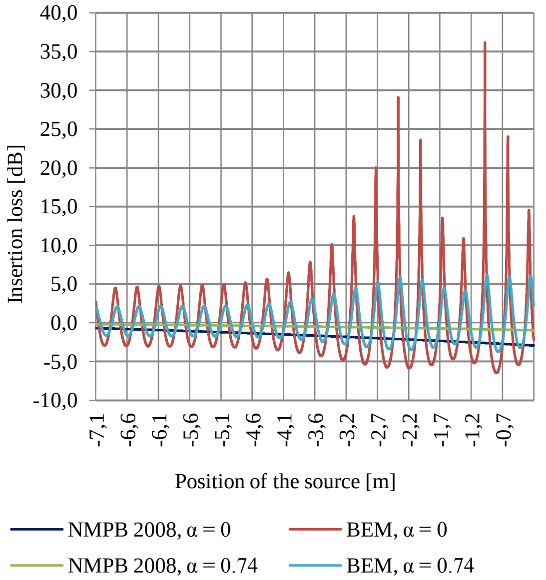

Fig. 10: The insertion loss, variant 1

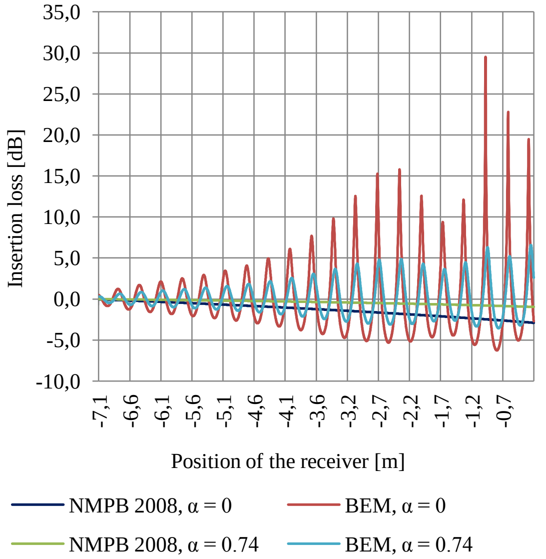

Fig. 11: The insertion loss, variant 2

8 Conclusion

The strategic noise mapping and consequent action plans were supposed to reduce the number of inhabitants in the EU member countries who are affected by excessive noise load. The process of noise mapping initiated several research projects. The aim of these research projects was to find out the best way how to determine the noise load caused by road, railway and air traffic and industrial activities.

It can be stated that to this day nearly each EU member country has its own calculation procedures for accessing noise levels and different legislation concerning this topic. Although united standards for strategic noise mapping are compulsory, there are no obligatory international regulations for common acoustic studies.

The problem of choosing the right method is also complicated by the necessity to find a compromise between the precision on one side and the calculation time and verifiability on the other (an interested reader can learn more about this problem in Ref. 11).

It is convenient when an engineering calculation procedure can be checked easily with a spreadsheet processor; otherwise the calculations become non-transparent and difficult to revise. As an outcome not only different engineers but also different implementations of software packages might vary in their results.

Precision is a quality which is appreciated primarily by researchers and scientists. It is a quality which is undoubtedly important but it is practically restricted by the possibility of getting the precise input data. When calculating the noise load in large areas (even entire cities) the input data are usually not very precise. After that, the calculation procedure can be far more precise than the input data itself.

The boundary element method is a numerical method based on the solution of the Helmholtz equation. Due to high demands on the calculation time, this method is not used in ordinary noise mapping. It is, however, very suitable for the verification of common engineering algorithms.

The image source method (the disadvantage of which is the energetic sum of the reflected and the direct sound ray) is mostly used nowadays for the reflection from a vertical obstacle. In this paper the verification of this weakness was processed with the BEM. The results calculated by the image sources method were compared with the quadratic curve fitted to the values obtained by the BEM.

It can be concluded that the image sources method is on the safe side. For a reflective screen the average deviation from the BEM was more than 1 dB (the average differences were 1.71 dB and 1.35 dB). When the absorption coefficient was modified (α = 0.74) the average differences were still on the safe side but lower (0.56 dB a 0.43 dB). Provided that the precision of other parts of the overall calculation procedure is taken into account these differences are acceptable.

Higher precision is probably not possible without considering the sound wave interference but, on the other hand, implementing this physical phenomenon into the calculation would prolong the calculation time and make the calculation more complicated. The calculation procedure would therefore become less transparent and more difficult to check.

It is also useful to mention the fact that the measurement of the sound pressure level close to a road includes many moving point sources with different sound power levels. Such measurement also proceeds for a certain time and consequently the result of this measurement tends not to differ much from the result calculated by an engineering algorithm.

It is therefore impossible to make a simple conclusion that a more precise method is also more convenient for practical purposes. The key to success is to find a compromise between a complexity of a method and taking into account of all the physical phenomena which can occur in a particular situation. The calculations shown in this paper confirmed that the image source method fulfils this principle.

Literature:

1. CHANDLER-WILDE, S. N. HOTHERSALL, D. C. *Efficient calculation of the Green function for acoustic propagation above a homogeneous impedance plane*. Journal of Sound and Vibration. 1995, 180, 705 – 724, ISSN 0022-460X.
2. *Directive 2002/49/EC of the European Parliament and of the Council relating to the assessment a management of environmental noise*, 25. 6. 2002.
3. DS/ISO 9613-2. *Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation.* Copenhagen: Dansk Standard, 1997.
4. HUNTER, P. PULLAN, A. *FEM/BEM Notes.* [online]. New Zealand: Department of Engineering Science, The University of Auckland, 2001. [cit. 25. 9. 2013]. Available at: http://www.cs. rutgers.edu/~suejung/fembemnotes.pdf.
5. JUHL, P. HENRIQUEZ, V. *OpenBEM – "Open source Matlab codes for the Boundary Element Method"* [online]. Institute of Technology and Innovation, University of Southern Denmark, 2011. [cit. 25. 9. 2013]. Available at: http://www.openbem.dk/.
6. KEPHALOPOULOS, S. PAVIOTTI, M. ANFOSO-LÉDÉE, F. *Common Noise Assessment Methods in Europe (CNOSSOS-EU).* Luxembourg: Publications Office of the European Union, 2012. ISBN 978-92-79-25282-2.
7. MECHEFSKE, C. K. *Sound Absorbing Materials and Sound Absorbers.* [online]. Kingston: Queen's University, Mechanical Engineering, 2010. [cit. 25. 9. 2013]. Available at: http://me. queensu.ca/Courses/482/Topic9-Soundabsorbingmaterialsandso undabsorbers.pdf.
8. NIELSEN, T. A. *Modelling the Influence of Noise Barriers on Road Noise by Using the Boundary Element Method.* 2012. Odense. Diploma thesis. University of Southern Denmark. Institute of Technology and Innovation.
9. NOTA, R. BARELDS, R. MAERCKE, D. et al. *Harmonoise WP 3 Engineering method for road traffic and railway noise after validation and fine-tuning*. No. Deliverable 18. 2005.
10. *Road noise prediction, 2: NMPB 2008 - Noise propagation computation method including meteorological effects.* [online]. Paris: Sétra, 2009. [cit. 25. 9. 2013]. Available at: http://www. setra.equipement.gouv.fr/IMG/pdf/US_0957-2A_Road_noise_ predictionDTRF.pdf.
11. PROBST, W. *New Techniques in Noise Prediction.* [online]. In: Proceedings of 20th International Congress on Acoustics, ICA, Sydney. 23. – 27. 8. 2010. [cit. 2.5.2013]. Available at: http://www.datakustik.com/fileadmin/user_ upload/PDF/Papers/ ICA2010_Noise_Prediction.pdf.
12. XP S 31-133. *Calculation of sound attenuation during outdoor propagation, including meteorological effects.* 1. ed. Paris: French Standards Association (AFNOR), 2001.

Primary Paper Section: J

Secondary Paper Section: JN