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Preface

The IEEE Russia North West Section, IEEE Russia Section, Saint Petersburg Electrotechnical University “LETI”, National Research University of Electronic Technology "MIET", and Glyndwr University, UK are pleased to present the Proceedings of the 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (2019 ElConRus) held in St. Petersburg and Moscow, Russia on January 28 - 30, 2019. This conference is proudly hosted by two universities - Saint Petersburg Electrotechnical University “LETI” and the National Research University of Electronic Technology "MIET". The Organising Committee believes and trusts that we have been true to the spirit of collegiality that members of IEEE value whilst also maintaining a high standard as we reviewed papers, provided feedback and now present a strong body of published work in this collection of proceedings.

The themes for this year's conference were chosen as a means of bringing together the many orientations of electrical and electronic engineering research and teaching, and providing a basis for discussion of issues arising across the young engineering community in relation to electrical and electronic engineering.

The aim in these proceedings has been to present high quality work in an accessible medium, for use in the teaching and further research of all people associated with electrical and electronic engineering studies. To achieve this aim, all abstracts were blind reviewed, and full papers submitted for publication in this journal of proceedings were subjected to a rigorous reviewing process.

Dr. Mikhail Shestopalov
Co-chair of the Conference Organizing Committee, Chair of the IEEE Russia NW Section

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Engineering Geometrical Acoustic Method for Higher-Order Diffraction of Sound in Building

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***Abstract*— Calculation of noise in the environment has been the subject of research for many years. Modern noise standards are based on simple algorithms of the "sound ray detour" method, which is implemented in ISO 9613-2, the most common standard used in Russia and Europe. The method of "detour" can be used without a special program. However, it can generate non-physical effects in the expected sound fields. The Nord2000 standard uses advanced wave-based diffraction procedures, but it is limited to two diffraction events and also causes some uncertainty in the prediction. Geometric acoustic methods are easier to implement and do not require large computer resources.**

Here we demonstrate an improvement of a standard "detour" method due to implementation of an energy transmission mechanism from the noise source to a secondary and higher order sources. We also present comparison of results with other calculation methods and results of measurements that demonstrate a good agreement of the proposed method to the reality.

Keywords—noise; geometrical acoustic; diffraction; building; detour method

I. INTRODUCTION (OVERVIEW OF EXISTING METHODS)

Today, the exposure of people to noise is one of the most serious problems since it affects the human health. The results of noise mapping in Europe held according to the Environment Noise Directive [1] show that 33% of European population suffer from increased environmental noise levels. About 56 million of people are affected by road noise, 9 million suffer of railroad noise and about 1 million is exposed to industrial noise. Similar figures were obtained for Russia where one third of population is exposed to noise levels exceeding the limits [2].

Since 2002, the Environmental Noise Directive calls for the monitoring of noise and the creation of action plans in Europe. Monitoring of noise situation is executed using noise mapping. Noise maps also serve as a basis for the development of action plans.

For the creation of noise maps, the very simplified sound propagation models, such as [3,4] are currently applied. In Russia we use even more simplified method, provided by [5] and based mostly on ISO 9631-2.

Calculation methods are implemented in different software products such as SoundPLAN, CadnA and Predictor in Europe or Ecolog-Noise, ExNoise and ARM Acoustics in Russia. However, these applied estimation methods have to be improved to prevent uncertainties in analysis of acoustical situation. The experience of noise evaluation shows that more accurate simulation methods can reduce costs in the planning stage.

Models of sound propagation can be divided into wave theoretical approaches and methods of geometric acoustics. The first group views sound as waves; the second group assumes that sound propagates as particles of energy. Because of its complexity, the methods of theoretical wave modeling can be applied only to low frequencies and small volumes. Geometric acoustic methods provide for the propagation of sound through direct rays from noise sources to the calculated points. Geometrical acoustics methods are applicable for large volumes and even for entire cities [6].

Geometric acoustics methods consider only specular reflections, so wave effects, such as sound scattering on uneven surfaces or diffraction around corners, cannot be modeled with them. The distribution of noise has been studied quite well. However, the development of a general diffraction model still causes considerable difficulties, since the problem of higher order diffractions and their combinations with reflections has not been solved. At the same time, in the development of sound propagation paths, caused by diffraction of higher orders, are dominant. Another problem is determining the most appropriate sound propagation paths. Because it is not obvious which path of sound propagation makes a greater contribution to the sound field. This problem is associated with a simplified approach used in methods of modeling of geometric acoustics.

This paper describes the diffraction behind buildings, that are quite high compared with the height of the noise source and the calculated point. Small objects are not taken into account.

Currently there are numerous theories of diffraction. The first group consists of wave theoretical methods. This includes all diffraction theories that fully comply with the wave theory without any approximations. The second group approximates a wave field with Kirchhoff's assumptions. Most of the approaches in this group do not take into account the actual shape of the edges. There are other approaches that use Kirchhoff's assumptions to calculate the sound reflected from a rough surface. The third group approximates the diffraction

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theory even more, and takes into account only passing of sound around an obstacle.

The qualitative explanation of the theory of diffraction is represented by the principle of Huygens. Its main idea is that any wave can be created by superposition an infinite number of secondary sources. These secondary sources should be located at the wave front and radiate sound into the sphere. The superposition of the wave fronts of these secondary sources will create the same waveform as the original wave. For a plane wave, the side components of these secondary sources compensate each other, while the propagating part of the original wave consists of these secondary sources. With the introduction of an obstacle orthogonal to a plane wave, it shields the lower secondary sources, so that only the remaining upper secondary sources form the wave front behind the screen. The energy from the upper secondary sources spreads to the shadow zone, while the shielding effect of the lower secondary sources causes a decrease in energy in the unshielded zone.

The second group of diffraction models approximates the theoretical deviations of the waves, using Kirchhoff's assumptions. These models take into account both the direct sound and the diffracted sound field. Because of the assumptions made, these models cannot be used for high frequencies. In addition, the classical Kirchhoff assumption is valid only for small diffraction angles. To apply the Kirchhoff assumptions, it is necessary to use simplifications of the shielding surface. This surface is defined as an endless wall, which is divided into solid sections and holes. A typical Kirchhoff assumption is that the sound pressure on the back side of the solid wall is zero, and the sound field propagating through the holes does not change. In both assumptions, it is assumed that the hole is sufficiently large relative to the wavelength, so that diffraction effects act only inside the volume, that is, on the back of the hole.

Stephenson and his colleagues developed the idea of diffraction, based on uncertainty, in which particles deflect through “virtual walls” that extend from the diffraction edges. This method is known as the sound particles diffraction (SPD). It can be represented as follows: the gun produces point particles in different directions. The particle moves in the environment in accordance with the geometric laws. At a meeting with a wall, a particle can be reflected (specular or diffuse) or pass through it. The diffraction angle is determined by calculating the diffraction edges bending path, which is then used to obtain the effective hole width “b”, which is then substituted into a simple formula derived from the Fraunhofer diffraction theory.

Unfortunately, the diffraction estimate based on the uncertainty method causes a recursive separation of particles, and, consequently, an exponential increase in the computation time.

The SPD method has proven its usefulness in situations with a point source and small obstacles. As an example, a difficult situation was considered in [7] that creates problems for detour methods. Two ideally reflecting parallelepipeds, horizontally displaced relative to each other (Fig. 1a), are considered. The parallelepipeds are quite long and high, so that the diffraction of sound on the far edges does not make a significant contribution to the sound field. In addition, the reflection of the sound comes only from the parallelepipeds themselves. The results of the calculation using two methods are presented in Figure 1: the results of the calculation using the SPD method are shown in figure (a), and the results of the calculation using ISO are shown in figure (b).

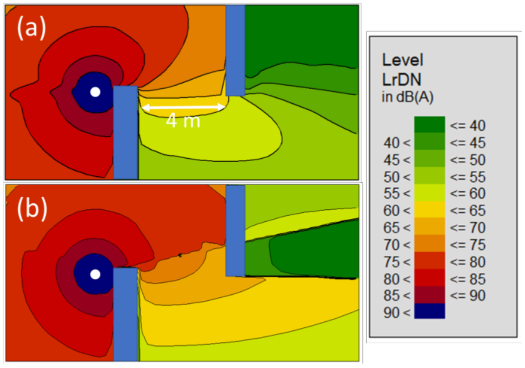

Figure 1 – Sound level field map showing diffraction through a gap between two offset blocks. Panel (a) shows sound particle diffraction results, panel (b) shows results from ISO 9613-2. The source is indicated by white dots, 500 Hz, 100 dB sound power

The ISO standard method estimates the path of sound from a source to a calculated point that passes through several edges. This path always has either an exceptionally right turn or an exceptionally left turn. This means that this method is not applicable to the zigzag arrangement of obstacles, as shown in Figure 1. As a result, we see a dark green area in Fig. 1 (b) where a certain amount of sound energy goes. The field is bounded by sharp gaps marking the transition points between the calculated diffraction values. The SPD method provides a smoother sound field, because particles can spread zigzag and pass a shorter path through the opening.

Another wave-based method, Nord2000, can be used to calculate propagation of sound from the linear source. The source is divided into a number of point sources with a step of less than 5 degrees. The contributions of point sources are estimated taking into account the type and surface topography in the Fresnel zone, which is formed around the reflected beam (Fig.2). The Fresnel zone is formed at the intersection of the Fresnel ellipsoid with the surface of the earth. The screening effect is evaluated from wave diffraction theory combined with geometrical theory, reflections from obstacles is handled by adding a mirror source using a Fresnel - zone approch. The method is valid only for double screens and for wedge angle grater than π [4].

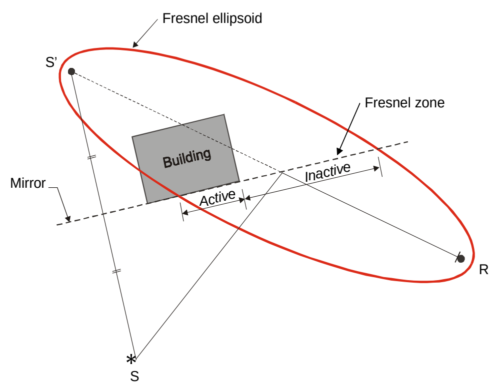

Fig. 2. Geometric model for Nord2000 method

The roughest approximation of the wave theory is to take into account only the shortest path through which sound travels from the noise source to the receiver, bending around an obstacle. These models are most often used to evaluate the effectiveness of thin acoustic screens. The most common model is the method of Maekawa [8]. It was based on empirical measurements. The result of Maekawa's experiments is a graph with non-linear axes, but usually a simple mathematical expression is used:

$$\Delta L = 10log10(20N) \qquad (1)$$

with $N = \frac{2d}{\lambda}$, where d stands for the detour that sound has to travel around an obstacle, and λ is the wavelength.

Maekawa method can be extended for the case of a thick barrier adding up an effect of thickness provided by an experimental chart as it is shown in Figure 3.

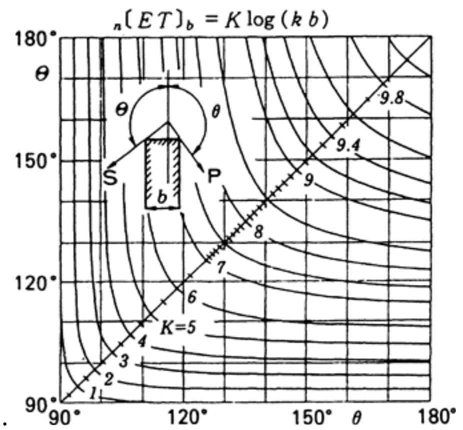

Fig. 3. Chart for obtaining the effect of thickness *b* of a noise barrier by Maekawa

A chart from figure 3 is still used in Russia to describe diffraction on two edges in case of a standard building located along the linear noise source [5].

Maekawa detour method is also laid in the basis of ISO 9631-2. In this standard, the value or sound attenuation at the presence of more than one edge is manually limited with 25 dB.

Thus, diffraction methods should be significantly improved in computational techniques, since they can significantly overestimate sound levels in the deep shadow zone, and, in addition, they can underestimate the levels in the shallow shadow. When they are applied, non-physical effects may occur that do not exist in reality. Deviations from more accurate methods may exceed 10 dB.

So, as we can see from the analysis of existing methods used to evaluate diffraction, they cannot be applied directly for the case of a linear source, such as traffic flow, and for multiple diffraction edges. In this work, the detour method of Maekawa is used as a basis for further improvements and creation of the engineering geometrical acoustic method for evaluation of diffraction in building from the linear source. To refine the detour method more recent advances and considerations provided by [9] are used.

II. METHOD FOR EVALUATION OF DIFFRACTION IN BUILDING

The engineering method is based on the theory of acoustics developed by Z. Maekawa and improved by N. Ivanov. In the developed theory, buildings are considered as secondary noise sources that convert the sound field of the source on the way of its propagation to the receiver. During the conversion, the following basic parameters are taken into account:

1. Parameters of the sound field of the noise source;
2. Existence of absorbing surfaces in the path of noise propagation;
3. Dimensions of buildings and sound absorption properties of their facades;
4. Location of buildings in relation to each other and to the noise source;
5. Reflection of sound on buildings' elements.

Calculations are performed in accordance with the rule provided by [8] and illustrated in Figure 4:

$$W_{source} \to I_1 \to W_1 \to I_2 \to W_2 \to \cdots \to I_n \to W_n \to I_{receiver} \qquad (2)$$

where W_{source} is the acoustic power of the source;

I_1 is the sound intensity on the first surface with the first impedance and W_1 is the acoustic power of sound emitted by this surface;

I_2 and W_2 are the same for the second surface with a new impedance;

I_n and W_n are the same for the n-th surface;

$I_{receiver}$ is the sound intensity at the receiver.

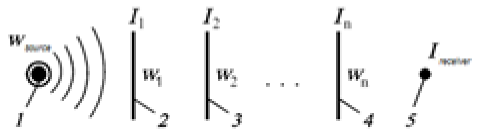

Fig. 4. Illustration to the rule of calculation:
1 – sound source; 2, 3, 4, ..., n – transitional surfaces; 5 – receiver

The initial value for the calculations is the acoustic power of the source (W_{source}), the final value is the sound intensity at the receiver ($I_{receiver}$).

Using the above approach, mathematical modeling was performed for the main cases of sound propagation in residential buildings. The most spread case is diffraction behind the long building that is presented below. Calculation scheme for estimating the diffraction of sound behind the building is presented in Figure 5.

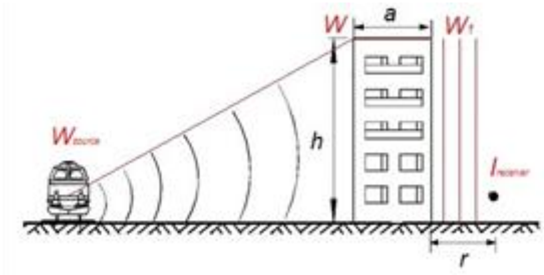

Fig. 5. The scheme (not to scale) for calculating the diffraction of sound behind the building

The energy emitted by the noise source, such as the traffic flow, is distributed along the facade of the building faced to the noise source. The sound level at the building propagated from the noise source is evaluated using provisions of ISO 9613-2. Some part of the sound energy is absorbed by the surface of the facade of the building due to its sound absorption coefficient.

The secondary source is presented by a linear source of a finite length equal to the length of the building l, m, with a width that we will assume equal to 1 m. The acoustic power of the secondary source is defined as:

$$W = I_{eq} \times (1-\alpha) \times l \times 1, \text{ W} \quad (3)$$

where *Ieq* is the intensity of the sound of the traffic, W/m^2; α is the sound absorption coefficient of the facade of the building; *l* is the length of the building, m.

Assuming that the sound in the upper part of the building is emitted by a linear source of a length *l* for a distance equal to the width of the building *a*, for which the condition $a \le l/\pi$ is fulfilled, then the sound intensity on the side of the building opposite to the sound source is defined as:

$$I_1 = \frac{W_1}{2\pi la} arctg \frac{l}{2a}, \text{W/m}^2 \quad (4)$$

The acoustic power of a flat sound source with a length l and a height h located on the side of the receiver, is evaluated as:

$$W_1 = I_1 \times l \times h, \text{ W} \quad (5)$$

The sound intensity at the receiver located at a distance *r* from the building that does not exceed

$r \le 0{,}4\sqrt{S}$ is determined by the formula:

$$I_{receiver} = \frac{W_1}{\pi lh} arctg \frac{lh}{2R\sqrt{4R^2+l^2+h^2}}, \text{W/m}^2 \quad (6)$$

Substituting all into (7), making the necessary reductions and conversions, we get:

$$I_{receiver} = \frac{I_{eq}(1-\alpha)}{2\pi^2 a} arctg \frac{l}{2a} arctg \frac{lh}{2R\sqrt{4R^2+l^2+h^2}}, \text{W/m}^2 \quad (7)$$

Dividing both parts by the standard sound threshold we get the final sound level for case of deep sound shadow presented at the scheme in Figure 5:

$$L_{receiver} = L_{eq} + 10\lg(1-\alpha) - 10\lg a + 10\lg arctg \frac{l}{2a} + 10\lg arctg \frac{lh}{2R\sqrt{4R^2+l^2+h^2}} - 13 \text{ dBA} \quad (8)$$

The proposed approach can be extended to the cases of multiple diffractions using the rule provided in Figure 4. Also, this method combined with evaluation of reflection can be used to evaluate noise reduction behind the aperture between the buildings and for different anomalous diffraction situations.

III. RESULTS AND DISCUSSION: COMPARISON WITH OTHER METHODS AND RESULTS OF MEASUREMENTS

To evaluate the results obtained with the proposed method, the noise levels for the situation presented in Figure 6 were measured. A building of the length of 200 m and width of 12 m is situated along the road. The noise levels were measured in front of the building and behind it. The results of measured noise reduction compared to the calculated levels are presented in Figure 7.

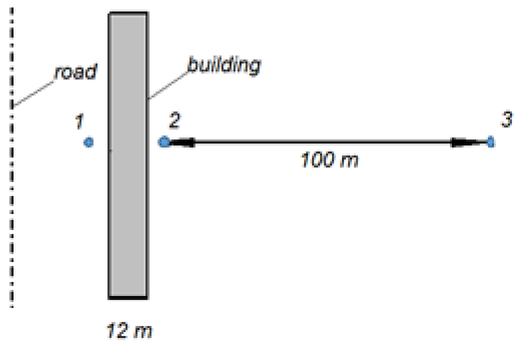

Fig. 6. The scheme (not to scale) for measurements of noise: receivers 1-3 are situated in front of the building, right behind the building and at the distance of 100 m behind the building.

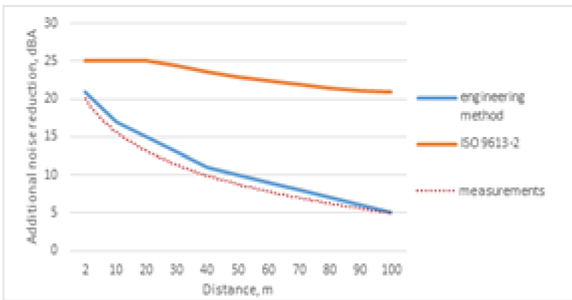

Fig. 7. Comparison of results obtained with the proposed method, using ISO 9613-2 and results of measurements

The analysis of the results of comparison show that the proposed method gives better results than the standard procedure applied in ISO 9613-2. It was noted that the ISO 9613-2 method can underestimate the levels in the shadow zone and overestimate the additional noise reduction. There is also an unphysical effect shown as a flattening at the curve. The more detailed procedures, such as proposed engineering method, are able to avoid it and provide better estimation of noise reduction due to its diffraction over the building.

IV. CONCLUSIONS

1. It is shown that existing methods used to evaluate diffraction cannot be applied directly for the case of a linear source, such as traffic flow, and for multiple diffraction edges.

2. The engineering geometrical acoustic method, based on the refined detour method, was designed for evaluation of diffraction in building.

3. It is shown that this diffraction procedure can represent a significant improvement over existing standard methods coping the cases that can be difficult to handle with other methods.

4. The designed method shows a good agreement to the results of measurements.

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