DESIGN-EXPERIMENT APPROACH TO THE DEVELOPMENT OF NOISE MAPS

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According to the opinion of physicians, about 30 percent of the population morbidity in cities is caused by the influence of the high-intensive acoustical fields. On the scope of the influence and acuteness of diseases this factor takes the third place after water and air pollution in Saint-Petersburg. The influence of acoustical fields not only causes discomfort but also leads to such diseases like worsening of hearing, mental and cardiovascular disorders. With the investigations held in early 90-ties it was defined that not less than 50 percents of population were under influence of acoustical fields significantly exceeding the legitimate values. During last decades due to the increase of transportation, worsening of operation of industrial objects and other reasons the influence of acoustical fields has increased almost twice and amount of population suffering from this factor has increased up to 70 percents. The investigations showed that almost one fourth of population of Saint-Petersburg lives in so called "black" and "gray" areas where the noise level significantly exceeds legitimate values.

For control and prediction of noisiness in the biggest cities of Russia, such as Moscow, Saint-Petersburg, Nizhniy Novgorod, Novosibirsk and some others, the noise maps were created. The development of these maps was based on the data collected during acoustical measurements. Let's examine the properties of these maps and acoustical situation in the cities on the example of Saint-Petersburg [1]. Firstly, we shall focus on the acoustical map of Saint-Petersburg (fig. 1). At the map we can see the lines of different colors marking the equivalent sound levels, dBA, measured at the main highways of the city. The colored lines at the map have the following meanings:

- yellow – less than 65 dBA;
- orange – 66-70 dBA;
- red – 71-75 dBA;
- violet – 76-80 dBA;
- blue – 81-85 dBA.

According to the results of the analysis of measured sites it is easy to define that the noise levels at the majority of highways equal to 65-80 dBA. Comparing these data with the sanitary code for the habitation (55 dBA on the daytime) one can see that there is an excess of 10 to 25 dBA or 2 to 5 times by the subjective feeling of loudness.

This fact states that the noise levels at the traffic lines of Saint-Petersburg are very high. At the same time it is easy to notice the limited nature of presented results. Evidently, these data are related to the most loaded traffic lines of the city. Only a small part of the urban territory, about 10 percent of the total city area, was examined. These data are quite enough for the rough estimation of the urban noise but they are not sufficient for the decision of the operational problems of the city.

In reality, for the reconstruction measures and new building and for purchase and exchange of premises, the planning organizations and citizens need more full information on the equivalent noise levels not only at the main lines but at the habitation territory as the whole. It is very difficult to imagine that the measurements of the whole city area can be executed. The only way out

of this situation is the development of calculation models describing the noisiness. This approach is used by the foreign specialists, especially in Germany [2], where a great experience of noise mapping is accumulated. The calculation models are based on the classical theory of noise propagation [3,4] and on some recent developments made in Japan [5] and Russia [6].

The classification of design models was developed in Saint-Petersburg. Its main positions are presented in table 1. The input data for the calculation are taken from the map [1]. We would like to notice that the suggested calculation method is based on the character of noise propagation in the habitation building and not on the evaluation of noise in dependency of the amount and structure of the transport line at the examined spot. Along with the experimental ones these data can serve as the basis for theoretical calculations of noise propagation.

Firstly, we shall examine the diffraction of sound over and round the building (see fig. 2 a,b)

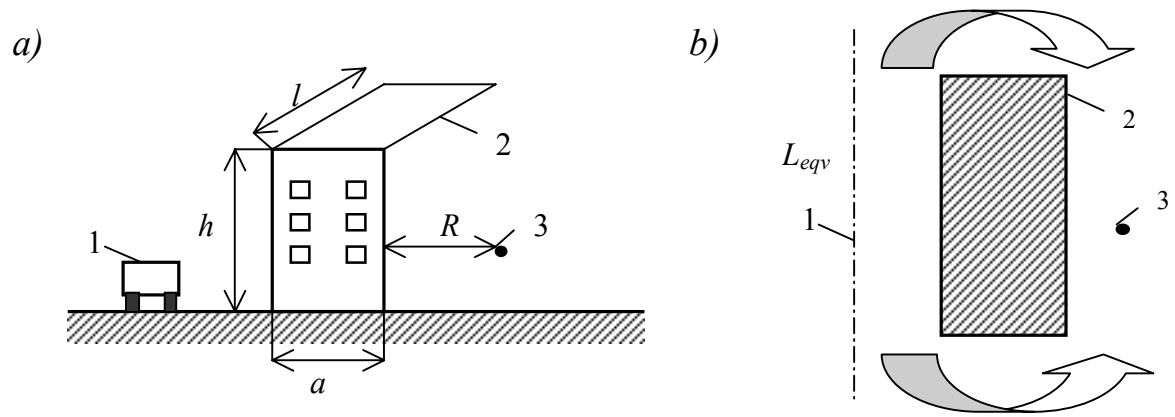


Figure 2. The scheme of sound diffraction over (a) and round (b) the building
1 – traffic line, 2 – separate building, 3 – reference point

Let us imagine that the energy is equally disseminated on the wall nearest to the source of sound (traffic line). Then the linear radiator equaled to the length of the building l can be treated as the secondary sound radiator. The width of the dotted radiator is conditionally assumed to be equal to 1 m, then the acoustical power of this radiator is defined as:

$$W = I_{eqv} \times l \times 1, \text{ watt} \tag{1.1.}$$

where I_{eqv} – is the sound intensity of the traffic line, watt/m^2;
l – length of the building, m.

Let's assume that the sound in the upper side of the building is radiated by the linear radiator of the length l at the distance equaled to the width of the building. Then the intensity on the side of the building opposite to the sound source is defined as:

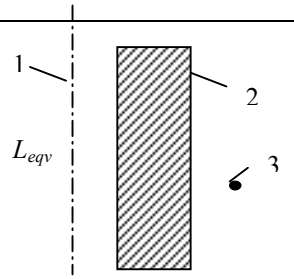
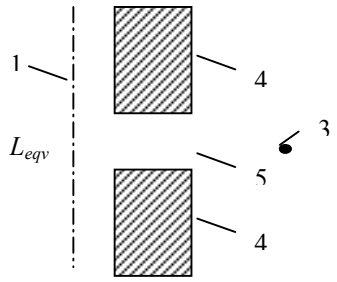
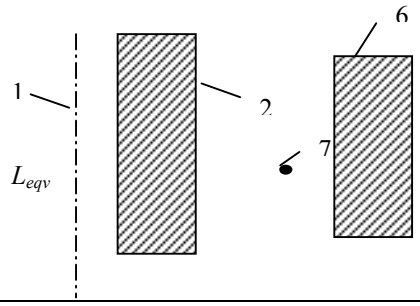
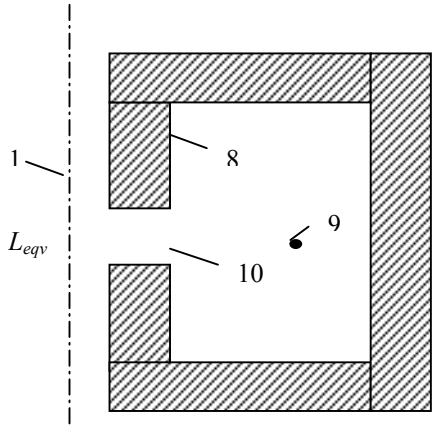
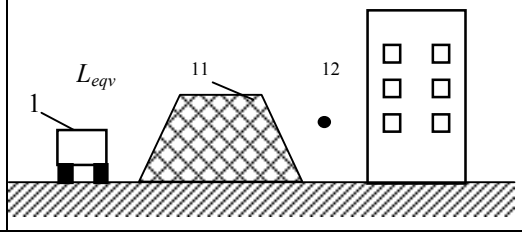
$$I_1 = \frac{W}{2\pi la} arctg \frac{l}{2a}, \text{watt/m}^2 \tag{1.2.}$$

The acoustical power of the radiator situated at the side of the reference point is:

$$W_1 = I_1 \times l \times h, \text{ watt} \tag{1.3.}$$

Classification of design models

Table 1

#	Scheme	Symbols at the scheme	Noise propagation properties
1.		1 – traffic line, 2 – separate building, 3 – reference point	The sound diffracts round the separate building to the reference point situated nearby the building
2.		4 – two neighboring buildings with the gap (5)	The sound propagates to the reference point through the gap between the buildings
3.		6 – the building situated behind the other building (2) 7 – reference point	The sound propagates to the reference point situated far from the building nearest to the traffic line
4.		8 – building forming the closed volume 9 – reference point inside the volume 10 – gap	The sound propagates to the reference point through the gap and grows in the closed volume
5.		11 – embankment 12 – reference point	The sound diffracts round the embankment

The intensity of sound in the reference point situated at the distance R from the building is defined by the following formula:

$$I = \frac{4W_1}{\pi lh} arctg \frac{lh}{2R\sqrt{4R^2 + l^2 + h^2}}, \text{ watt/m}^2 \quad (1.4.)$$

If we substitute the formulas (1.1.)-(1.3.) to the (1.4.) and make some simplifications and transformations we shall get the following:

$$I = \frac{2I_{eqv}}{\pi^2 a} arctg \frac{l}{2a} arctg \frac{lh}{2R\sqrt{4R^2 + l^2 + h^2}}, \text{watt/m}^2 \quad (1.5.)$$

After that we divide the both parts to the standard sound threshold and find the logarithm. The final sound level for the first design model from the table 1 will be defined as:

$$L = L_{eqv} - 10\lg a + 10\lg arctg \frac{l}{2a} + 10\lg arctg \frac{lh}{2R\sqrt{4R^2 + l^2 + h^2}} + 3, \text{dBA} \quad (1.6.)$$

It's easy to notice that in the given example the sound diffracts over the building. The formula (1.6.) does not consider the propagation of sound round the building. The calculation with use of this formula will be right if $h \leq 2l$. In the opposite case the sound propagating round the building is defined similarly but we take the linear radiator of the length h as the secondary radiator. Here:

$$W' = I_{eqv} \times h \times 1 \quad (1.7.)$$

$$I_1 = \frac{W'}{2\pi ha} arctg \frac{l}{2h}, \quad (1.8.)$$

$$W_1 = I_1 \times h \times a, \quad (1.9.)$$

$$I = \frac{W_1}{2\pi hR} arctg \frac{h}{2R}, \quad (1.10.)$$

If we substitute (1.7.)-(1.9.) to the (1.10.), make transformations and find the logarithm, we'll have:

$$L = L_{eqv} - 10\lg R + 10 arctg \frac{h}{2R} arctg \frac{l}{2h} - 16, \quad (1.11.)$$

Let's make the calculations for the design scheme 2 presented in table 1. In this case the sound energy propagates through the gap between the buildings (fig. 3).

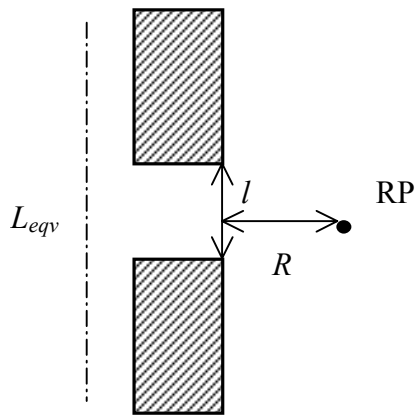


Figure 3. Design scheme of sound propagation to the reference point (RP) through the gap between the buildings

Where R is the shortest distance from the source of the length l to the reference point.

The intensity of sound in the reference point is the same:

$$I = \frac{W}{2\pi l_{gap} R} arctg \frac{l}{2R}, \text{watt/m} \qquad (1.12.)$$

The value W can be defined with the assumption that the sound is radiated by the secondary radiator:

$$W = I_{eqv} \times l_{gap} \times 1, \text{ watt} \qquad (1.13)$$

If we substitute (1.13.) to the (1.12.) and make transformations, we'll have:

$$L = L_{eqv} - 10 \lg R + 10 \lg acrtg \frac{l}{2R} - 8, \text{dBA} \qquad (1.14.)$$

Let us now examine the example when the reference point moves away at the distance R that is much more than the size of the source, $R > l$ (fig. 4).

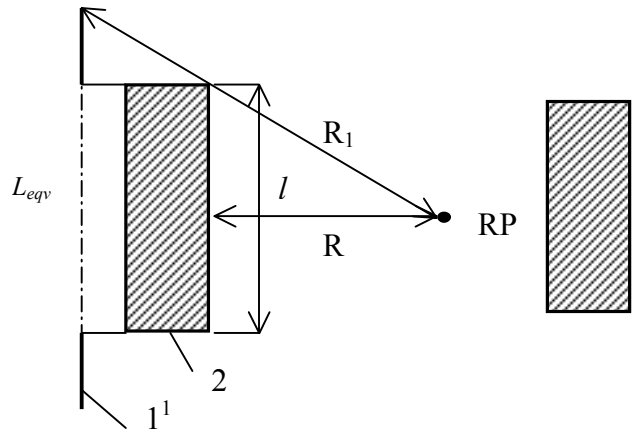


Figure 4. The design scheme for the situation when the RP is situated at the distance $R > l$
1^1 – a part of traffic that eliminates the sound to the RP, 2 – building

In this case we can suppose that the main contribution to the noise accumulation in the RP is made not by the diffraction of the sound over the building but by the sound propagated from the part of the traffic from the both sides of the building. We'll assume that the sound is radiated by the site behind the building equaled to *l/4.* Then using the above argumentation on the character of the radiation made by the gap and assuming that the RP is situated symmetric for the both sides of the building, we'll have:

$$L = L_{eqv} - 10 \lg R_1 + 10 \lg arctg \frac{l}{8R_1} - 3, dBA \qquad (1.15.)$$

where R is the distance from the noise source to the RP, m.

The main feature of noise accumulation for the scheme 4 presented in table 1 is the existence of both damping of the noise and its reverberation in the closed volume. The noise energy in the RP can be defined as the sum of direct and reverberated sounds (fig. 5).

$$I_{RP} = I_{dir} + I_{rev} \tag{1.16.}$$

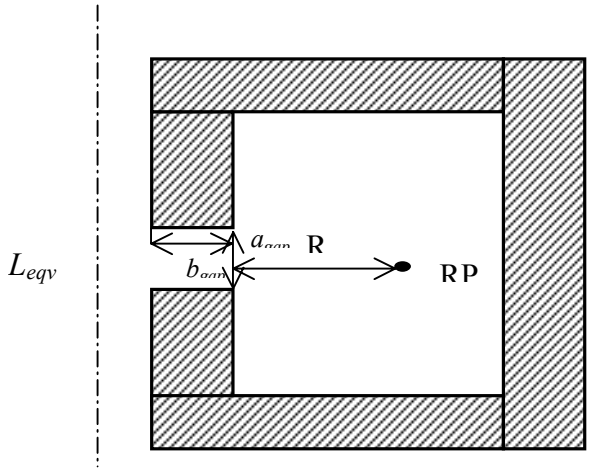


Figure 5. The design scheme for calculation of the sound level in the closed volume

The value of intensity is defined with the assumption that the sound is radiated to the RP by the plate radiator, the gap:

$$I_{dir} = \frac{4W_{gap}}{\pi a_{gap} b_{gap}} arctg \frac{a_{gap} b_{gap}}{2R\sqrt{4R^2 + a_{gap}^{\ 2} + b_{gap}^{\ 2}}}, \text{ watt/m}^2 \tag{1.17.}$$

Here

$$W_{gap} = I_{eqv} \times a_{gap} \times b_{gap}, \text{watt} \tag{1.18.}$$

where a_{gap} and b_{gap} are the linear dimensions of the gap.

The value of reverberated intensity is defined as:

$$I_{rev} = \frac{4W_{gap}}{B_{c.v.}} \tag{1.19.}$$

where $B_{c.v.}$ is the acoustical constant of the closed volume, m^2.

$$B_{c.v..} = \frac{\sum_{i=1}^{n} \alpha_i S_i}{(1 - \overline{\alpha}_{c.v.})} \tag{1.20.}$$

$$\overline{\alpha}_{c.v.} = \frac{\sum_{i=1}^{n} \alpha_i S_i}{S_{c.v.}} \tag{1.21.}$$

where α_i is a coefficient of the i frame filling with the square equaled to S_i, m^2; $\overline{\alpha}_{c.v.}$ is the average sound-absorbing coefficient of the closed volume; $S_{c.v.}$ – square of the closed volume, m^2.

If we substitute (1.18.) to the (1.17.), (1.20.) and (1.21.) to the (1.19.) and after that the received formulas to the (1.16.), we'll have:

$$I_{RP} = 4I_{eqv}\left[\frac{1}{\pi}arctg\frac{a_{gap}b_{gap}}{2R\sqrt{4R^2 + a_{gap}^{\ 2} + b_{gap}^{\ 2}}} + \frac{a_{gap}b_{gap}(1-\frac{\sum_{i=1}^{n}\alpha_i S_i}{S_{c.v..}})}{\sum_{i=1}^{n}\alpha_i S_i}\right], \quad (1.22.)$$

Finding the logarithms of the both parts, we'll finally receive:

$$L = L_{eqv} + 10\lg\left[\frac{1}{\pi}arctg\frac{a_{gap}b_{gap}}{2R\sqrt{4R^2 + a_{gap}^{\ 2} + b_{gap}^{\ 2}}} + \frac{a_{gap}b_{gap}(1-\frac{\sum_{i=1}^{n}\alpha_i S_i}{S_{c.v.}})}{\sum_{i=1}^{n}\alpha_i S_i}\right] + 6, dBA \quad (1.23.)$$

The propagation of the sound to the point separated from the traffic line by the embankment can be defined with the following assumptions (fig. 6).

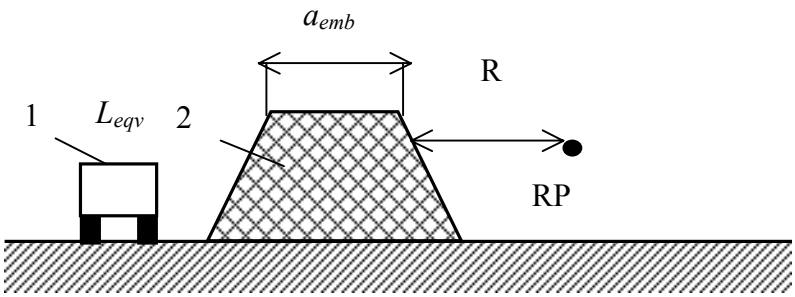


Figure 6. Design scheme for sound propagation from the traffic line (1) over the embankment (2) with the length l_{emb}

The sound diffracts over the embankment to the reference point situated at the distance R from the embankment. The sound power at the side of the traffic line is:

$$W = I_{eqv} \times l_{emb} \times 1, \quad (1.24.)$$

where l_{emb} is the length of the embankment, m.

The intensity of sound at the side of the embankment opposite to the traffic line is defined with the assumption that the edge of the embankment is the secondary linear source of the sound:

$$I = \frac{W(1-\alpha_{emb})}{2\pi l_{emb}a_{emb}} arctg\frac{l_{emb}}{2a_{emb}}, \quad (1.25.)$$

where l_{emb}, a_{emb} – length and width of the embankment, m; α_{emb} is the sound-absorbing coefficient of the embankment.

Let's assume that the sound is radiated to the RP by the secondary source with the acoustical power defined as:

$$W_{rad} = I \times l_{emb} \times 1, \quad (1.26.)$$

The intensity of sound in the RP is defined as:

$$I_{RP} = \frac{W_{rad}}{2\pi l_{emb} R} arctg \frac{l_{emb}}{2R}, \qquad (1.27.)$$

If we substitute (1.24.)-(1.26.) to the (1.27.) and make simplifications, we'll receive:

$$I_{RP} = \frac{I_{eqv}(1-\alpha_{emb})}{(2\pi)^2 a_{emb} R} arctg \frac{l_{emb}}{2R} arctg \frac{l_{emb}}{2a_{emb}}, \qquad (1.28.)$$

Finding the logarithms of the both parts, we'll finally have:

$$L = L_{eqv} + 10\lg(1-\alpha_{emb}) - 10\lg R - 10\lg a_{emb} + 10\lg arctg \frac{l_{emb}}{2R} + 10\lg arctg \frac{l_{emb}}{2a_{emb}} - 22, dBA \qquad (1.29.)$$

With use of the computer program *ArcView GIS* the given calculation model developed with use of the above approach is imposed to the electronic map of the city. In result of the work the detailed small-scale electronic map is obtained. It allows to give the objective evaluation of the acoustical pollution created by the traffic lines in the habitation building with account of the timing data and characteristics of their operation. The map can be used for the evaluation of the new building territories and prediction of the prospective noisiness in the city territories, for the determination of the most appropriate methods of noise reduction and further planning of the building with regard to the traffic lines and other sources of noise.

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