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EVALUATION OF THE EFFECTS OF THE GREEN PLANTINGS STRIP ON THE SPATIAL DISTRIBUTION OF NOISE LEVEL FROM THE ROAD TRAFFIC

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Abstract

The article is devoted to the evaluation of the influence of the green plantings strip in reducing noise pollution levels around highways using an analytical model which takes into account the combined influence of other noise reduction factors. As the initial data of the calculation the full-scale measurements of noise levels on the selected profiles of the Central part of the city of Kharkiv, located on a busy Main street with high traffic intensity and adjacent to the residential area were taken.

On the basis of the study, the parameters of the model components describing the influence of various factors of attenuation of the acoustic flow intensity were determined, and it was found that the contribution of ordinary green belts in the overall reduction of the physical impact of traffic noise can be close to 40%.

Key words: traffic, noise level, green space, analytical model.

Formulation of the problem.

In modern conditions of human existence, the problem of noise exposure and measures to protect against it has reached significance and is further developed. The effect of noise is continuous and it increases the overall anthropogenic load of the environment. The main source of noise pollution in the cities is the motor transport.

Analysis of recent research and publications.

In her paper [1] Vnukova N. V. considers the direct impact of the vehicle-road-environment complex and notes that car roads affect the environment at all stages of their existence, from the construction to full operation of the road. With the development of the city's infrastructure, the acoustic discomfort zones increase [2]. Noise impact on the acoustic environment in cities is almost always local in nature and is mainly caused by the vehicles, while the vehicles have the most adverse effect, since cars are the predominant sources of intense and prolonged noise and, moreover, are distributed throughout the city [3]. In 1993, the world health organization (WHO) recognized the following effects of noise on public health: disorders of sleep, cardiac, respiratory, psycho-physiological function, hearing aid. In the European Union, more than 40% of the population is exposed to road noise exceeding 55 dBA in the daytime and 20% – which exceeds 65 dBA [4]. The level of road noise depends on many factors: the number, structure and speed of the vehicles, road surface and slope, and the number of traffic lanes.

Problem setting and its solution.

In our opinion, one of the most appropriate ways to protect against noise in an urban environment is the introduction of green belts near the internal development roads. The authors propose to study and exarticulate the contribution of green spaces, the functions of which were not provided as "noise-protective", and located along the roadways, taking into account the architectural planning and aesthetic solutions in the design of residential buildings.

The aim of this work is to develop an analytical model for assessing the impact of СЗН (green belt, GB) on noise reduction according to the field observations.

One of the measures to reduce the impact of traffic noise on the population is the creation of green belts (GB) next to the roads. The sanitary norms and regulations which have been in force since 1997 [7] the recommendations for determining the effect of GB on noise reduction, depending on their composition and structure. In particular, it was proposed to create such strips of fast-growing trees and shrubs, arranged in the form of one, two or three rows with dense contiguity of tree crowns with a height of at least 5-8 meters and filling the space under the crowns down to the ground with bushes. Depending on the number of rows, the noise reduction behind the Green Belt was determined by the values from 4 to 12 dBA. According to Leushin P.I., the sound, getting into the crown, appears as if it was in another medium, which, having much more acoustic resistance compared to the air, reflects and dissipates about 74% of the sound energy and absorbs up to 26% [8]. Trees with dense crown and leaves – maple, poplar, linden, elm have high sound-absorbing ability [9].

As the new document has entered into force [5], the content of similar recommendations has changed significantly. So, for example, it is recommended to take the effect of noise reduction, which is provided by one -, two-and three-line structures of Green belts with dense contiguity of tree crowns and filling the space under the crowns with bushes, from 1 to 5.5 dBA for the first vegetation zone of the country and from 2 to 6.5 dBA for the third vegetation zone. This discrepancy in the estimates of the Green belt necessitates further study of the problem. In addition, the structures proposed in [5] do not cover the other possible green belt structures, such as those which are not inline.

In order to study the transfer of acoustic noise waves in green areas in October 2017 on Klochkivska Street in Kharkiv the experimental field measurements of noise levels in the adjacent green belts were carried out using the hybrid method. Along the street adjacent to the village area, two profiles were selected for field observations and measurements at a distance of 0 m, 10 m, 20 m, 50 m, and 100 m from a linear noise source.

Klochkivska Street is one of the largest motorways of the first category in Kharkiv city, which completely crosses the Shevchenkivskyi district and has a length of about 8 km. This highway has 4 lanes of traffic with an approximate traffic speed of 600 unit per hour per lane and serves to offload the traffic flow of the district and the central part of the city. Type of pavement is fine-grained asphalt concrete.

In particular, the reference time interval for averaging the instantaneous noise level records was determined by recommendations [10] based on the number of vehicles (at least 200 units) which produce the recorded noise. Measurements were taken with the noise meter of the DT 8852 model at ten points of the terrain, in accordance with the requirements [11] as for the weather conditions for the measurements, the placement of the instrument and the operator. The results of the evaluation of the equivalent noise levels by the second registrations of instantaneous noise levels during the period of relatively stable traffic from 1 pm to 2 pm are shown in Table. 1.

Table 1 Characteristics of the points of experimental studies of the noise pollution influence

Designation of experimental sites	Distance to the edge of the road, m	Lequ, dBA	Number of rows of plantations to the measuring point, pcs
TN3	0	77	0
	10	65	2
	20	62	3
	50	57	7
	100	57	12
TN4	0	76	0
	10	69	2
	20	61	3
	50	58	6
	100	56	12

Both profiles were laid in the park area of Kharkiv, where the coating of the wood tier ranged from 10% to 70%. It is known that a significant role in shaping the acoustic comfort of the city is played by a complex of architectural and planning decisions, in particular planting of greenery. At each profile, a sample of tree model was formed to evaluate their contribution to reducing noise pollution in the city.

Green belt profile of TN3 is represented by twelve rows of leafy maple, which is widespread in the territory of Kharkiv and can be used to study relationships between biotic components and physical factors of anthropogenic origin. The TN4 profile green belt is represented by mixed plantings. The species composition of the studied profile contains hearty linden and silver maple. The average height of trees on both profiles varies from 17 m to 25 m, only the linden trees represented in the TN4 profile have a height of 7.5 m. The average distance between tree crowns is about 5 meters.

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The study of the green belt effect on noise attenuation is complicated by the fact that this factor acts in conjunction with other factors which determine the distribution of noise intensity along the earth's surface. Among them, such phenomena as attenuation of noise due to the increase in the sound waves front area, due to the absorption of noise intensity when reflected from the earth's surface and due to the dissipation of energy of acoustic waves in the atmosphere, are always present. Let's look at each of these factors, which always work.

Acoustic wave front extension. It is advisable to consider a traffic stream on a straight line as a linear source of noise (thin filament) if equivalent noise levels are determined at distances well beyond the width of the road. This is due to the fact that the rules of street noise measurement in the field or near traffic lanes active in the country ([10, 11]) and abroad (for example, [12]) provide for determining the physical impact of noise at equivalent levels (dBA) for set reference time intervals of 15, 30, 60 minutes or more, depending on the purpose of the measurements.

In the daytime, due to the high frequency of registrations of the instantaneous noise levels, each vehicle leaves several markings recorded by the instrument from different positions on the road. In its turn, due to the considerable intensity of the movement, the positions of all vehicles, the noise of which is recorded during the reference interval of time, tightly cover the linear lane of the road. In this case, each registration makes a contribution equal to any of the others when the measurement results are averaged to determine the corresponding equivalent noise level. Thus, the result of averaging will look as if all the positions emit noise at the same time, creating a linearly distributed constant source of noise.

Due to the high velocity of sound propagation in the atmosphere (approximately 340 m / s), it can be assumed that the average radial flow of acoustic energy, if no other factors are acting, through any cylindrical surface not far away at a radius (up to a kilometer) from the roads and with the axles along the lane are constant:

$$\alpha \cdot r \cdot l \cdot J(r) = const\ , \qquad (1)$$

where α is the angle in radians between the lines which reflect the earth's surface at the cross-section of the road (corresponding to the horizontal surface $\alpha = \pi$);

r – the radius of the cylindrical surface of the wave front or the distance from the linear noise source, m;

l – the length of cylindrical surface along the road, m;

$J(r)$ – the average density of the radial flow of the acoustic energy at the distance r from the source, W/m^2.

The first derivative of equation (1), by coordinate r provides the equation for reducing the intensity of noise due to the increase of the acoustic wave front area:

$$\frac{dJ(r)}{dr} = -\frac{1}{r} J(r). \qquad (2)$$

Absorption by the Earth's surface. Ground-source noise is transmitted in the form of waves of two kinds – straight and reflected by the earth's surface. If the earth's surface was absolutely solid, then no noise energy was spent for reflection. However, in reality they do occur (for example, [5]). We believe that the rate of decrease of noise energy flow with distance from the source due to its absorption on the earth's surface is proportional to the specific extension of the sound wave front (r^{-1}) and the magnitude of the energy flow, i.e.:

$$\frac{dJ(r)}{dr} = -\frac{\beta}{r} J(r), \qquad (3)$$

where β – is a coefficient of acoustic energy loss on reflection from the earth's surface.

Noise energy dissipation in the atmosphere. Simultaneously with these factors the energy consumption of noise energy for internal friction and heat exchange, as well as dissipation of the acoustic energy at the atmospheric turbulence and the particles of atmospheric formations contribute to the attenuation of radiation from the linear source. [13, 14] The equation for the spatial velocity of this process can be taken as

$$\frac{dJ(r)}{dr} = -\gamma\, J(r), \qquad (4)$$

where γ is the noise attenuation factor.

The formulas given here determine the rate of decrease of the acoustic energy flow density along the path of propagation of noise from a linear source over the earth's surface.

Noise reduction in green belt. Specially arranged green belts or noise shields provide local reduction in acoustic energy flow [5, 7]. The attenuation of noise in the green belts is due to the absorption and dissipation of the acoustic energy flow on the leaves and shoots of trees and shrubs. Since the transfer of acoustic energy has a wave nature, it is a direct analogy with the phenomenon of extinction (attenuation) of the wave flow of light on inhomogenities in the atmosphere or in liquids. The equation corresponding to this analogy for the speed of decreasing the acoustic energy flow is taken as follows

$$\frac{dJ(r)}{dr} = -k(r) J(r), \qquad (5)$$

where $k(r)$ is a variable noise extinction coefficient in the atmospheric surface layer with variable acoustic density within the green belt, m^{-1}.

Joint influence of factors. If the above factors act simultaneously, independently of each other and are expressed by the above equations, then the total equation for the distribution of the noise energy from the road traffic stream over the distance is taken as

$$\frac{dJ(r)}{dr} = -\frac{1}{r} \cdot J(r) - \frac{\beta}{r} J(r) - \gamma\, J(r) - k(r) \cdot J(r). \qquad (6)$$

The solution of this ordinary first-order differential equation with separable variables can be given in the form of

$$\frac{J(r_0)}{J(r)} = \left(\frac{r_0}{r}\right)^{1+\beta} \cdot exp\left[\gamma \cdot (r - r_0) + \int_{r_0}^{r} k(s)\, ds\right], \qquad (7)$$

where $J(r)$ is the average density of the energy flow of sound waves at any distance r from a linear noise source, W/m^2;

$J(r_0)$ – the average density of the sound waves energy flow over a certain distance $r_0 \le r$.

The value

$$d(r, r_0) = \int_{r_0}^{r} k(s) ds \qquad (8)$$

can be called integral noise extinction in the green belt located in the road lane with the width of $r - r_0$.

Applying the logarithm for the equation (7), we find a formula which determines the reduction of the noise level in decibels at different distances r_0 and r from a linear noise source:

$$\Delta L(r, r_0) = 10(1 + \beta) lg\left(\frac{r_0}{r}\right) + 10 lg(e)[\gamma \cdot (r - r_0) + d(r, r_0)], \qquad (9)$$

where e is the basis of natural logarithms

Determination of model parameters. It is assumed that the coefficients β and γ in equation (9) can be determined from the data of the field observations. To test this possibility, a typical graph of noise level change under the influence of the considered factors, in addition to the influence of the green belts, was used in [7] in

Figure 26 The results of converting this graph into numbers are shown in Table 2 for the near (from 10 to 110 m) and far (from 10 to 1000) noise distribution areas at r_0 = 7.5 m.

Table 2 Distribution of the traffic noise level according to [15]

Near area		Far area	
r, m	$\Delta L(r)$, dBA	r, m	$\Delta L(r)$, dBA
10	1.5	10	1.5
20	5.4	100	15.4
30	7.7	200	20.3
40	9.5	300	23.2
50	11	400	25.5
60	12.2	500	27
70	13	600	28.3
80	13.9	700	29.2
90	14.7	800	30.2
100	15.4	900	31
110	16.1	1000	31.9

The feasibility of a separate analysis of the conditions of distribution of noise energy in the near and far zone from the road is determined by the possibility of changing the properties of the flow of acoustic energy at a distance from the source (for example, changing the spectral composition of noise).

The noise distribution equation for the approximation of the data in Table 2 is as follows:

$$\Delta L(r) - 10lg\,\frac{r}{r_0} = 10lg\,\frac{r}{r_0}\beta + 10\lg(e)(r - r_0)\gamma. \quad (10)$$

The best are the least-error-approximation coefficients β and γ are determined by the least squares method. Appropriate design dependencies have the form:

$$\beta = \frac{b\cdot f1 - c\cdot f2}{a\cdot b - c^2};\ \gamma = \frac{c\cdot f1 - a\cdot f2}{c^2 - a\cdot b}; \quad (11)$$

$$a = 100\sum_r lg^2\left(\frac{r}{r_0}\right);$$

$$b = 100 lg^2(e)\sum_r (r - r_0)^2; \quad (12)$$

$$c = 100 lg\,(e)\sum_r (r - r_0)\,lg\left(\frac{r}{r_0}\right); \quad (13)$$

$$f1 = 10\sum_r\left[\Delta L(r) - 10lg\left(\frac{r}{r_0}\right)\right] lg\left(\frac{r}{r_0}\right); \quad (14)$$

$$f2 = 10lg(e)\sum_r\left[\Delta L(r) - 10lg\left(\frac{r}{r_0}\right)\right](r - r_0). \quad (15)$$

Using the table values r gives $\Delta L(r)$ the following values of the coefficients which are determined:

– for the near zone β = 0.235 i γ = 0,0038 m^{-1};

– for the far zone β = 0.403 i γ = 0,00052 m^{-1}.

At this, in case of approximation for the near zone, the absolute error of model (9) was less than 0.17 dBA, and for the far zone it was less than 0.6 dBA.

Assessment of the green belt influence. The contribution of the green belts to noise reduction can be calculated from certain field measurements using model (9) as

$$d(r, r_0) = \frac{\Delta L(r, r_0) - 10(1+\beta)lg\left(\frac{r_0}{r}\right)}{10lg(e)} - \gamma\cdot(r - r_0), \quad (16)$$

where $d(r, r_0)$ is a reduction in noise within the green belts which are in the roadside with the width $r - r_0$, dBA;

$\Delta L(r, r_0)$ – noise reduction according to two measurements data at the boundaries of the strip of the width $r - r_0$, dBA;

β and γ – the coefficients, the value of which should be selected depending on the location of the green belt in the near or far zone of the road.

r_0 – distance from a linear noise source to the point of measurement of the noise level in front of the green belt border, m;

r – the distance of the second point of measurement of the noise level beyond the outer boundary of the breen belt, m.

The results of such an assessment by measurements in two experimental plots are shown in Table 3.

Table 3 – Estimation of noise reduction in the strip of green space according to the data of the field observations (r_0 = 7.5 m, β = 0.235 and γ = 0.0038 m^{-1})

Designation of experimental sites	$r - r_0$, m	$\Delta L(r, r_0)$, dBA	$d(r, r_0)$, dBA	$d(r, r_0)/\Delta L(r, r_0)$*100%
TN3	10	12	3.8	31.7
	20	15	5.0	33.3
	50	20	6.9	34.5
	100	20	7.5	37.5
TN4	10	7	2.6	37.1
	20	15	5.0	33.3
	50	18	6.5	36.1
	100	20	7.5	37.5

Conclusions.

Based on the results obtained, we can draw the following conclusions. Analytical model (9) of the distribution of the noise energy flow from a linear source, which is considered to be traffic, allows approximating the above typical data with high accuracy and can be used in further studies to assess the impact of different configurations of the green belts on reducing the road noise. Based on the field observations, it can be concluded that the noise reduction in the space adjacent to the transport highway due to the presence of green belts can approach 40% of the total reduction, even if these green belts have no special antinoise structure. So, for example, in the presence of two rows of plantings, we have a reduction due to Green belt from 2,6 dBA to 3,8 dBA, with a three-row landing noise load is reduced by 5 dBA, and in twelve rows of Green belt (only in cases where the road is adjacent to the park area), noise reduction reaches 7,5 dBA. The subsequent full-scale studies of noise distribution planned for different vegetation periods will allow for further verification of the adequacy of the model presented to assess the effect of the green belt influence on noise reduction and to select a model for estimating this effect by the characteristics of the composition and structure of the green belt.

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ОЦІНКА ВПЛИВУ СМУГИ ЗЕЛЕНИХ НАСАДЖЕНЬ НА ПРОСТОРОВИЙ РОЗПОДІЛ РІВНЯ ШУМУ ВІД ДОРОЖНЬОГО РУХУ

Стаття присвячена оцінці впливу смуг зелених насаджень у зниженні рівнів шумового забруднення навколо транспортних магістралей за допомогою аналітичної моделі, що враховує сумісний вплив інших факторів зниження шуму. У якості вихідних даних розрахунку було взято натурні виміри рівнів шуму на обраних профілях центральної частини міста Харків, що розташована на завантаженій магістральній вулиці з високою інтенсивністю руху автотранспорту та є прилеглою до зони житлової забудови.

На основі дослідження визначені параметри складових моделі, які описують вплив різних факторів послаблення інтенсивності акустичного потоку, і встановлено, що внесок звичайних смуг зелених насаджень у загальному зниженні фізичного впливу шуму транспортного руху може наближатися до 40%.

Ключові слова: транспортний рух, рівень шуму, зелені насадження, аналітична модель.

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ОЦЕНКА ВОЗДЕЙСТВИЯ ПОЛОСЫ ЗЕЛЕНЫХ НАСАЖДЕНИЙ НА ПРОСТРАНСТВЕННОЕ РАСПРЕДЕЛЕНИЕ УРОВНЯ ШУМА ОТ ДОРОЖНОГО ДВИЖЕНИЯ

Статья посвящена оценке влияния полос зеленых насаждений в снижении уровней шумового загрязнения около транспортных магистралей с помощью аналитической модели, учитывающей совместное влияние других факторов снижения шума. В качестве исходных данных расчета были взяты натурные измерения уровней шума на выбранных профилях центральной части города Харькова, расположенные на загруженной магистральной улице с высокой интенсивностью движения автотранспорта и является прилегающей к зоне жилой застройки.

На основе исследования определены параметры модели, описывающие влияние различных факторов ослабления интенсивности акустического потока, и установлено, что вклад обычных полос зеленых насаждений в общем снижении физического воздействия шума транспортного движения может приближаться к 40%.

Ключевые слова: транспортное движение, уровень шума, зеленые насаждения, аналитическая модель.