HIGH-SPEED TRAIN NOISE SOURCE HEIGHT INFLUENCE ON EFFICIENCY OF NOISE BARRIERS

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Sound field formed at high speeds of train movement (over 250 km/h) is generated by several noise sources located at different height. One of the contributions to the train sound field is aerodynamic noise emitted by the pantograph located on a train roof at the height of up to 5.0 m from the rail head. To determine effectiveness of noise barriers installed along the high-speed railways correctly it's necessary to consider contributions of noise sources located at different height. The paper presents the methodology allowing noise barrier insertion loss evaluation considering complex model of noise generation and different heights of separate noise sources of high-speed trains.

Keywords: noise, barrier, high-speed train, insertion loss.

1. Introduction

In previously published works [1, 2] new equations for high-speed trains noise prediction were proposed by the authors. The basis of the elaboration method is the representation of the high-speed train as a complex of three main noise sources (later on – NS): the 'wheel-rail' pair, the train body (mostly front part) and train pantograph. The proposed approach allows to take in accout the height of each separate noise source and, therefore, to determine the insertion loss of the noise barrier (later on – NB) for each of noise source separately and finally calculate complex influence of each noise source.

Noise barrier efficiency is its insertion loss estimated as the difference of sound pressure levels at the receiver position when there is no barrier and sound propagates directly from the noise source to the reciever and when the barrier is installed. Barrier efficiency significantly depends on noise source height. The calculation model of the noise barrier insertion loss considering different heights of the noise sources is presented in Fig.1.

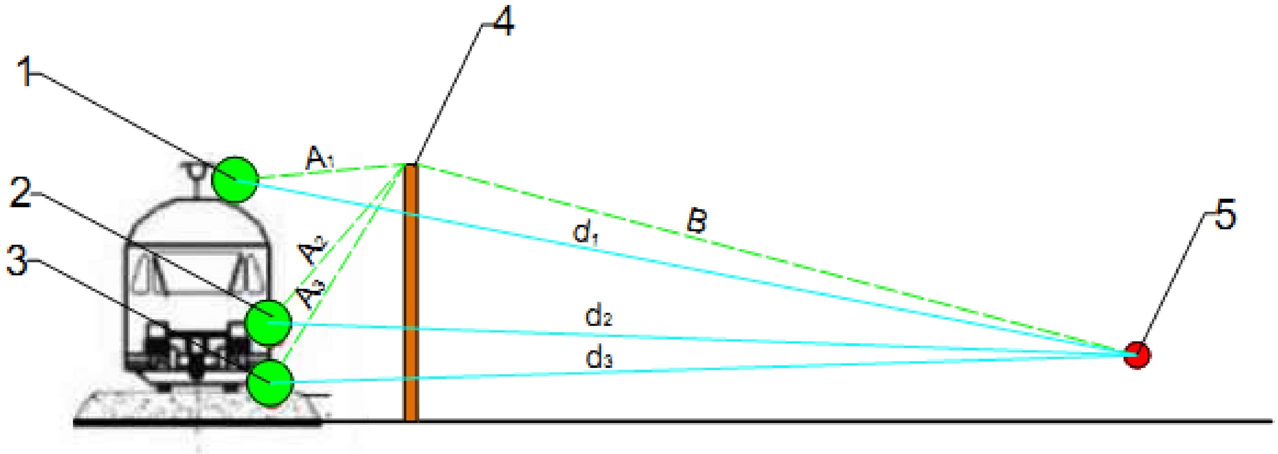

Figure 1: A calculation model for determination of the noise barrier insertion loss considrering high-speed train noise sources: 1 – a pantograph, 2 – the body and the front part of the train, 3 – the 'wheel-rail' pair, 4 – a noise barrier, 5 – a sensitive receiver

The green dotted lines at Fig. 1 represent sound propagation paths from the high-speed train noise sources to a sensitive receiver (later on – R), for the case when a noise barrier is installed. The blue straight lines represent sound way when no obstacles are between the train and the receiver. Following designations are used in the Fig. 1: $A_{1, 2, 3}$ are the distances from the particular NS (the first, the second and the third noise sources, respectively) and the top edge of the barrier; B is the distance from the top edge of the barrier to the receiver; $d_{1, 2, 3}$ are the distances between the particular NS (1, 2, 3) and the receiver.

2. Barrier insertion loss calculations

2.1 General consideration

It is found that particular noise reduction provided by a noise source in presence with a noise barrier depends on the effective height of the barrier (h_{eff}), which is determined as the difference between the perpendicular dropped from the centre of the noise source to the vertical axis of the barrier and the level of the barrier upper edge (Fig. 2).

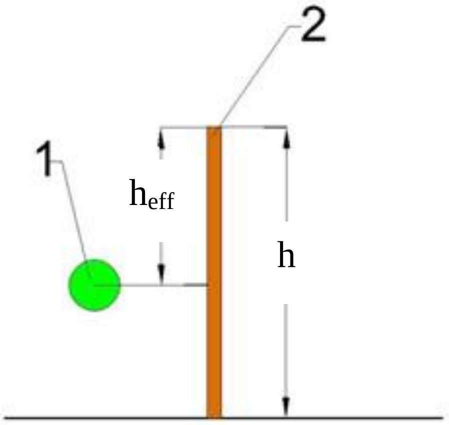

Figure 2: A calculation model for determination of the insertion loss of a noise barrier for each high-speed train noise source: 1 – a noise source, 2 – a noise barrier, h is the height of the barrier, h_{eff} is the effective height of the barrier

Taking into account particular heights of high-speed train main noise sources effective height of two noise barriers were considered (Table 1). Thus, with the installation of two barriers with the heights of 5 m and 8 m, their effective working heights will be determined by the values listed in Table 1.

Table 1: Barrier effective heights for each high-speed train noise source

Noise source	NS height, m	Barrier effective height for each noise source, m	
		Barrier height is 5 m	Barrier height is 8 m
Pantograph	5,0	0,0	3,0
Train front part and train body	2,0	3,0	6,0
'Wheel-rail' pair	0,5	4,5	7,5

It should be noted that with the effective barrier height 0 m, the insertion loss of a noise barrier is not equal to 0 dB. According to U. Kurtze's formula [3], when a noise source and a noise barrier are located on the same level respectively the ground, barrier insertion loss is equal to 5 dB (for a point noise source), based on the expression:

$$\Delta L_{NB} = \left\{ 20\lg \frac{\sqrt{2\pi\,|N|}}{tg\sqrt{2\pi\,|N|}} + 5, dB \right\} \quad , \tag{1}$$

where N is the Fresnel number defined by the formula:

$$N = \frac{2(A+B-d)}{\lambda} \quad , \tag{2}$$

where A, B, d are the distances, determined in accordance with Fig. 1, m;

λ is the wave length, m.

2.2 Analysis

According to ISO 3095:2013 [4] train noise shall be determined at a distance of 25 m from the axis of the nearest track at a height of (1,2±0,2) meters.

Determination of the train barrier insertion loss was made as an example according to the formulas of ISO 9613-2:1996 [5] for the following two cases:

1) the common approach: when a single noise source (a train) was considered at a height of 1.5 meters, and
2) the proposed approach: when a train is presentted by the combination of three noise sources: a 'wheel-rail' pair (located at 0.5 m), the train body and its nose (located at 2.0 m), and a pantograph (located at 5.0 m).

The calculations were made according to the following equation:

$$A_{bar} = 10\lg\left[3 + \left(C_2/\lambda\right) C_3\, z\, k_{met}\right] - A_{gr}, \text{ dB}, \tag{3}$$

where A_{bar} is the barrier insertion loss (efficiency), dB,

A_{gr} is the attenuation due to the ground effect if the barrier is absent, dB,

C_2, C_3 , k_{met} are corrections;

z is the difference between the path lengths of diffracted and direct sound, m.

The calculation of the barrier efficiency is done using the following initial data:

1) two barriers of the infinite length with the heights of 5.0 m and 8.0 m;
2) reflection from the ground is absent, C_2=20;
3) diffraction happens only on the upper edge, C_3=1 (diffraction on the side edges does not occur):
4) calculations are carried out for $\lambda = 0.34$ m for the frequency of 1000 Hz;

5) The distance from NS to the barrier is 4 m, the distance from the barrier to the receiver is 50 m;
6) Due to small distance between the noise source and the reciever (less than 100 m), the meteorological conditions coefficient is taken equal to unity, K_{met}=1;
7) Attenuation due to ground effect in the absence of the barrier is taken as 4.0 dBA.

2.2.1 Common approach

In calculations made by the equation (3) and initial data presented above for the height of the noise source 1.5 m the barrier insertion loss is 15,3 dBA (in case of 5,0 meters barrier height) and 19,8 dBA (in case of 8,0 meters barrier height).

2.2.2 Proposed approach

It is proposed to calculate insertion loss for each noise source of the high-speed trains separately. Barrier insertion loss estimated for the same initial data, but with different heights of the noise source is presented in Table. 2.

Table 2: Determination of the insertion loss of two barriers (5 m and 8 m heights) for different NS of high-speed trains

Noise source	NS height, m	Noise barrier insertion loss, dBA	
		Barrier height 5 m	Barrier height 8 m
Pantograph	5,0	5,5	15,3
Train front part and body	2,0	14,3	19,3
'Wheel-rail' pair	0,5	17,0	20,6

In comparison with U. Kurtze formula (1), ISO 9613-2:1996 methods for barrier insertion loss prediction provides similar results. For instance, if barrier height commensurate to the height of the noise source, or in case if the difference of the ray paths tends to zero, and in absence of ground absorption (with the high location of the noise source above the ground), the barrier insertion loss will be not less than the value 10lg(3)=4.8 dBA. Thus, the values obtained according to U.Kurtze's formula and according to ISO 9613-2:1996 are the same for the same conditions.

Let us consider ann example of a train moving at a speed of 380 km/h and having noise characteristics presented below at the maximum level, measured at 25 m from the axis of the nearest railroad track. Let us compare the obtained values of barrier insertion loss for considering three noise sources and just one noise source, i.e. representing the train as one source. The comparison of obtained results is made in Table. 3.

Table 3: Insertion loss of 5-meters barrier obtained by different prediction methods

<table>
<tr><th rowspan="2">Noise source</th><th colspan="2">Sound levels at 25 m, dBA</th><th colspan="2">Barrier insertion loss, dBA</th><th colspan="2">Sound levels with a barrier located at 54 m (without divergence), dBA</th></tr>
<tr><th>1 NS*</th><th>3 NS**</th><th>1 NS*</th><th>3 NS**</th><th>1 NS*</th><th>3 NS**</th></tr>
<tr><td>Pantograph</td><td rowspan="3">93,1</td><td>87,9</td><td rowspan="3">15,3</td><td>5,5</td><td rowspan="3">77,8</td><td>82,4</td></tr>
<tr><td>Train front part and body</td><td>86,9</td><td>14,3</td><td>72,6</td></tr>
<tr><td>'Wheel-rail' pair</td><td>89,9</td><td>17,0</td><td>72,9</td></tr>
</table>

*the whole train is considered as one noise source,

** the train is consídred as three noise sources.

Thus, the table shows that when applying the approach of splitting the train into three noise sources, the obtained values of barrier insertion loss takes into account its irregular work for the sources located at different heights. Particularly, rolling noise created by the ‘wheel-rail’ pair at a height of 0.5 m barrier insertion loss is by 12 dBA higher than for the noise of the pantograph at a height of 5.0 m.

If train is represented as one noise source at a height of 1.5 m the predicted barrier insertion loss is too high in relation to a number of sources, such as noise of the body and front of the train and the noise of the pantograph. At the height of 5,0 m difference of the sound levels in two calculation approaches at a distance of 54 m from the axis of the railway track reaches 4.6 dBA, and may cause significant errors in designing noise control measures. The same comparison is given for noise barrier with the height of 8 m (results are shown in Table 4)/

Table 4: 8-meters barrier insertion loss obtained by different approaches

Noise source	Max levels at 25 m, dBA		Barrier insertion loss 8 m, dBA		Levels with barrier of 54 m (without divergence), dBA	
	1 NS*	3 NS**	1 NS*	3 NS**	1 NS*	3 NS**
Pantograph	93,1	87,9	19,8	15,3	73,3	72,6
Train front part and body		86,9		19,3		67,6
‘Wheel-rail’ pair		89,9		20,6		69,3

*the whole train is considered as one noise source,

** the train is consididred as three noise sources.

As follows from made estimation if a 8-meter barrier is installed, difference in insertion loss for the pantograph with two approaches is 0.7 dBA, and for rolling noise is 4.0 dBA.

3. Conclusion

Representation of high-speed trains by three noise sources allows to obtain more accurate information for determinatoin of barrier insertion loss. Without considreng the train as three individual noise sources with different heights, sound levels in reference points after applying noise protection measures can vary up to 5 dBA for high and low sources, which may be a cause for designing the barriers of insufficient height, not effective against the noise of the pantograph.

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