Projected Multifunctional Hotel Complex Noise Level Prediction from Railway Trains Passing (JSC “Russian Railways” Connecting Branch Section) with Sound Insulation Measures Development

I E Tsukernikov¹, L A Tikhomirov¹, T O Nevenchannaya¹,²
¹Acoustic Laboratory, Research Institute of Building Physics, 21 Lokomotivny pr., Moscow, 127238, Russia
²Press and Media Industry Higher School, Moscow Polytechnic University, 2A Pryanishnikova str., Moscow, 127550, Russia

E-mail: niisf@mail.ru

Abstract. One of the important stages of work in the building design is to assess the level of comfort and safety of people during the operation of the building. Prediction of the acoustic situation in the premises and in the territory allows, even at the design stage, to take measures to protect against noise. This is especially true of traffic noise. In this paper, forecasting and assessment of railway noise levels in the territory adjacent to the multifunctional hotel complex under construction and in the apartments of the complex are carried out, based both on the results of field measurements and on the results of calculations made by the methods of the interstate standards GOST 33325, GOST 31295-2 and the code of rules SP 276.1325800 using the data provided by GAU “Institute of the General Plan of Moscow”. The required sound insulation of the facades of the buildings of the complex is determined and constructions of sound protection windows are proposed.

1. Introduction

It is noted in the report of the Government of Moscow “On the state of the environment in the city of Moscow in 2017” [1] the need to design acoustic sound protection measures (installation of noise screens and special glazing of windows in residential buildings and social facilities) for new construction projects in case calculations predict that the permissible noise levels will be exceeded. The object of forecasting in this work is the hotel complex, which includes two 20-storey buildings, in which apartments are located from the 2nd to the 20th floors. The main sound source, which can have a negative impact on the acoustic environment, is the section of the railway located at a distance of 25 m from the designed complex.

To predict the noise impact in the apartments of the designed hotel complex from the adjacent railway line, it is necessary to calculate the expected levels of normalized noise parameters during the time of assessment (16 hours at day and 8 hours at night) 2 meters from the facades of the buildings, considering the railway as an extended sound source. In view of the non-constant nature of noise, the normalized parameters in accordance with SN 2.2.4/2.1.8.562-96 [2], are the equivalent and maximum A-weighted sound pressure levels (sound levels).
The noise characteristics of passing train flows for the specified assessment time are used as the initial data for the calculation. In accordance with GOST 20444 [3], GOST 33325 [4] and SP 276.1325800 [5], these characteristics are equivalent ($L_{\text{Aeq25}}$) and maximum ($L_{\text{Amax25}}$) sound levels, determined at a distance of 25 m from the axis of the main path closest to the designed object, and at a height 1.5 m above the rail head level (hereinafter, the notations from [4] are used).

In this paper, we determined the noise characteristics of trains and train flows plying the railway section adjacent to the projected hotel complex, calculated the expected sound levels of railway noise at a distance of 2 m from the facades of the complex’s buildings, estimated the required sound insulation and, for each facade, proposed constructions of the soundproof windows that provide the specified soundproofing of the facades and ensure compliance with noise regulations in the apartments of the complex for both current and future billing periods of time.

2. Determination of the noise characteristics of trains and train flows

According to the data provided by the GAU “Moscow Master Plan Institute”, on the branch in question, mainly suburban passenger traffic takes place, including 100 pairs of suburban trains per day, moving at a speed of 40-50 km / h, and long-distance passenger traffic in the form of three pairs of trains moving at a speed of 60 km / h. Freight traffic is absent. At the same time, for the prospective calculation period, the intensity of the suburban passenger traffic increases to 150 train pairs per day, long-distance passenger traffic decreases to two train pairs per day. In the daytime, 85 pairs (for a calculated period 135 pairs) of suburban trains and one pair of long-distance passenger trains run. At night 15 pairs of suburban trains and two pairs of long-distance trains run for the current time and for the calculation period.

2.1. Noise characteristics of trains

Because of the impossibility of direct measurement, the noise characteristics of suburban trains and their flows were taken in accordance with the formulas GOST 33325-2015 [4], SP 276.1325800 [5]:

for equivalent sound levels

$$L_{\text{Aeq25,3}} = 28.9\lg \nu_3 + 10\lg \arctg \left( \frac{l_3}{25} \right) + 28,$$

(1)

for maximum sound levels

$$L_{\text{Amax25,3}} = 27.1\lg \nu_3 + 37.2,$$

(2)

where $\nu_3$ is the train speed of the 3rd category (suburban train), km/h; $l_3$ is the train length, m.

(Further, for brevity, the index 3 will be omitted.)

The calculation was performed on the basis of the parameters obtained from the field measurements, including the transit time and the length of the suburban trains. Field measurements of sound levels during the passage of trains were performed at a distance of 10 m from the axis of the near lane.

For comparison with the results of field measurements, the calculated sound levels at a distance of 25 m from the railway were recalculated into the corresponding sound levels at a distance of 10 m from the railway using the expression:

$$L_{\text{A10}} = L_{\text{A25}} + 10\lg 2.5.$$  

(3)

The averaging (by energy) of all values obtained in the calculation and measurement was carried out. Also, the sound levels were calculated using the value of average length of suburban trains recommended in [4, 5] $l = 200$ m and the maximum value of speed of suburban trains indicated in the data of GAU “Institute of the General Plan of Moscow” $\nu = 50$ km/h. The results of calculations, the data of field measurements and averaged values are given in table 1.
The difference between the average (over energy) measured and calculated maximum sound levels is 2.8 dB(A), and between equivalent sound levels is 1.1 dB(A). When calculating by the average length of suburban trains of 200 m and maximum speeds of movement of suburban trains of 50 km/h, the discrepancies decrease to 0.9 dB(A) and 0.8 dB(A), respectively, i.e. do not exceed 1 dB(A). Such indicators suggest that the calculation results are fairly accurately correlated with the results of field measurements, and therefore, the calculated noise characteristics (for a distance of 25 m) can be used to calculate the expected sound levels 2 m from the facades of buildings. In this case, the calculations will use higher values of the noise characteristics \( L_{\text{eq25}} = 78.7 \, \text{dB(A)}, \, L_{\text{max25}} = 83.2 \, \text{dB(A)} \), obtained using the average length of suburban trains recommended in [4, 5] \((l_b = 200 \, \text{m})\) and long-distance passenger trains \((l_l = 500 \, \text{m})\) and the maximum speeds of commuter and passenger trains specified in the information of GAIU “Institute of the General Plan of Moscow” \((\nu_3 = 50 \, \text{km/h}}, \, \nu_1 = 60 \, \text{km/h})\).

For passenger long-distance trains, the calculation was performed according to the formulas [4, 5]: for equivalent sound level:

\[
L_{\text{eq25,1}} = 25.3 \, \nu_1 + 10 \left[ \arctg \left( \frac{l_l}{25} \right) \right] + 33.3 \quad (4)
\]

for maximum sound level:

\[
L_{\text{max25,1}} = 24 \, \nu_1 + 42.6 \quad (5)
\]

where \( \nu_1 = 60 \, \text{km/h} \) and \( l_l = 500 \, \text{m} \) are the speed of movement and the length of trains of the first category (passenger train).

The calculated values are: \( L_{\text{eq1}} = 80.1 \, \text{dB(A)}, \, L_{\text{max1}} = 85.3 \, \text{dB(A)} \).
2.2. Noise characteristics of train flows

The noise characteristics of the train flows during the evaluation time of 16 hours at day and 8 hours at night were determined taking into account the information on the intensity of train traffic on the considered section of the railway for the current and estimated periods provided by GAU “General Plan Institute of Moscow”. The equivalent total sound level \( L_{\text{eq,sum}} \) for the time \( T \) was estimated by the formula [4, 5]:

\[
L_{\text{eq,sum}} = 10 \log \left( \frac{1}{T} \left( t_1 n_1 10^{0.1L_{\text{eq1}}} + t_3 n_3 10^{0.1L_{\text{eq3}}} \right) \right),
\]

where \( t_1 \) and \( t_3 \) are the average passage time of the passenger and suburban trains through the reference point, \( n \) (based on average train lengths, maximum speeds of their movement and taking into account the rate of change in sound level as trains approach and remove in accordance with recommendations of GOST 31296.2 [6] adopted equal to: \( t_1 = 35 \text{ s}, t_3 = 20 \text{ s} \) \( n_1 \) and \( n_3 \) are the numbers of passenger and suburban trains passing through the reference point during the assessment period (in accordance with the information provided by GAU “General Plan Institute of Moscow”, the information is taken to be equal for the current period: during the day time \( n_1 = 2, n_3 = 170 \) at night \( n_1 = 4, n_3 = 30 \); for the calculation period - during the day time - \( n_1 = 0, n_3 = 270 \) (at night \( n_1 = 4, n_3 = 30 \)); \( L_{\text{eq1}} \) and \( L_{\text{eq3}} \) are the equivalent sound levels of a passenger and suburban train, dBA, defined in clause 2.1 \( (L_{\text{eq1}} = 80.1 \text{ dBA}, L_{\text{eq3}} = 78.7 \text{ dBA}); T \) is the evaluation time, equal to 16x3600 = 57600 s for the day and 8x3600 = 28800 s for the night.

The noise characteristic in the form of the maximum sound level corresponds to the data obtained in the previous subclause. Received noise characteristics of train flows are shown in Table 2.

### Table 2. Noise characteristics of train flows.

| Period of assessment | Day          | Night        |
|----------------------|--------------|--------------|
|                      | \( L_{\text{eq,sum}}^{16} \) dBA | \( L_{\text{eq,16}}^{\max} \) dBA | \( L_{\text{eq,sum}}^{8} \) dBA | \( L_{\text{max,8}}^{\max} \) dBA |
| Current              | 66.5         | 85.3         | 63.1         | 85.3         |
| Perspective          | 68.4         | 85.3         | 63.1         | 85.3         |

3. Calculation of the expected sound levels at the building facades and determination of the required sound insulation

Based on the obtained noise characteristics of the train flows, the expected sound levels were calculated at points near the facades of buildings at a height of 1.5 m from the second and 20th floor levels. The absolute values of the heights are 6 m and 65 m. In total, 20 points were allocated for the calculation: five points for the specified heights of each building. Two points were selected from the sides of the north-east and south-west facades of each building and six points on the sides facing the railway on the south-east facades of both buildings having a rugged structure. The scheme of the designed complex and railway section with measuring and calculating points is shown in Figure 1.

The calculation was performed using the software complex “ARM Acoustics” (version 3.2.6), which implements the provisions of GOST 31295.2 [7] (which is the introduction in the Russian Federation of the International Standard ISO 9613-2) as a calculation methodology.

The calculation results take into account the total standard uncertainty \( \sigma \) of the calculated noise parameters, estimated according to GOST 33325 [4]. In this case, the standard uncertainty of the method for determining the noise characteristics is determined by RMG 43 [8] (formula (5) based on the results of statistical processing of the measured values of sound levels (Table 1) and amounted 0.76 dBA for the equivalent sound level and 1.29 dBA for the maximum sound level. The standard uncertainty of the method for calculating noise levels at a calculation point in accordance with [4] is assumed to be 1 dBA. As a result, the following values were obtained for \( \sigma \): for the equivalent sound level of 1.26 dBA; for the maximum sound level of 1.63 dBA.
Figure 1. The scheme of the designed complex and railway section with measuring (MP) and calculating (CP) points.

(CP 1/2- CP 10/2, CP 1/20- CP 10/20 are the calculation points at the second and 20th floor levels)

As the results of the calculation of the expected sound levels in the calculated points, the upper boundaries of the trust intervals $L_{\text{lim}}(CP)$ are taken, defined by the expression

$$L_{\text{lim}}(CP) = L_A(CP) + k s_i$$

(7)

where $L_A(CP)$ is the equivalent or maximum sound levels to be calculated using the software complex “ARM Acoustics” at the calculation point, dBA; $k$ is the coverage factor, taken depending on
the confidence level (the value of the confidence probability) and the choice of the type of the coverage interval (two-sided or one-sided).

Since the purpose of the calculation is to compare with permissible sound levels, one-sided coverage interval should be adopted, for which, at the engineering confidence level \( (P = 95\%) \), \( k = 1.65 \). As a result, the expanded uncertainty takes on the values: \( k_u = 2.1 \text{ dBA} \) for an equivalent sound level; \( k_u = 2.7 \text{ dBA} \) for maximum sound level.

The results of calculation are shown in Table 3 for the calculated points CP 1/2 – CP 10/2 located at the second floor level, and in Table 4 for the calculated points CP 1/20 – CP 10/20 located at the level of the twentieth floor.

### Table 3. Expected noise levels at the level of the second floor for day and night periods.

| Calculation point | Day | Night |
|-------------------|-----|-------|
|                   | Current period | Perspective | Current period | Perspective |
|                   | \( L_{\text{eq,lim}} \), dB | \( L_{\text{max,lim}} \), dB | \( L_{\text{eq,lim}} \), dB | \( L_{\text{max,lim}} \), dB | \( L_{\text{eq,lim}} \), dB | \( L_{\text{max,lim}} \), dB | \( L_{\text{eq,lim}} \), dB | \( L_{\text{max,lim}} \), dB |
| CP 1/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 2/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 3/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 4/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 5/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 6/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 7/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 8/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 9/2            | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |
| CP 10/2           | 69.7 | 85.5 | 62.7 | 64.7 | 60.7 | 62.7 | 60.7 | 62.7 |

Considering that the permissible noise levels in the area immediately adjacent to the hotel buildings are 60 dBA at daytime and 50 dBA at night for the equivalent sound level and 75 dBA and 65 dBA for the maximum sound level, we obtain significant excess noise levels at all calculated points located at the height of the second floor. The highest elevation values are obtained on the sides facing the railroad and are 10.8 dBA during the day and 17.4 dBA at night for building A and 9.3 dBA during the day, 15.9 dBA at night for building B. The exceeding maximum sound levels are 15.2 dBA and 25.2 dBA, respectively for day and night periods for Building A and 11.2, 22.1 dBA for Building B.

### Table 4. Expected sound levels at the level of the 20th floor for day and night periods.

| Calculation point | Day | Night |
|-------------------|-----|-------|
|                   | Current period | Perspective | Current period | Perspective |
|                   | \( L_{\text{eq,lim}} \), dB | \( L_{\text{max,lim}} \), dB | \( L_{\text{eq,lim}} \), dB | \( L_{\text{max,lim}} \), dB | \( L_{\text{eq,lim}} \), dB | \( L_{\text{max,lim}} \), dB | \( L_{\text{eq,lim}} \), dB | \( L_{\text{max,lim}} \), dB |
| CP 1/20           | 58.5 | 78.2 | 60.4 | 78.2 | 55.1 | 78.2 | 55.1 | 78.2 |
| CP 2/20           | 62.1 | 79.3 | 64.0 | 79.3 | 58.7 | 79.3 | 58.7 | 79.3 |
| CP 3/20           | 62.5 | 78.8 | 64.4 | 78.8 | 59.1 | 78.8 | 59.1 | 78.8 |
| CP 4/20           | 61.3 | 78.7 | 63.7 | 78.7 | 57.9 | 78.7 | 57.9 | 78.7 |
| CP 5/20           | 58.3 | 76.9 | 60.2 | 76.9 | 54.9 | 76.9 | 54.9 | 76.9 |
| CP 6/20           | 59.0 | 77.6 | 60.9 | 77.6 | 55.6 | 77.6 | 55.6 | 77.6 |
| CP 7/20           | 61.8 | 78.4 | 63.7 | 78.4 | 58.4 | 78.4 | 58.4 | 78.4 |
| CP 8/20           | 62.2 | 78.8 | 64.1 | 78.8 | 58.8 | 78.8 | 58.8 | 78.8 |
| CP 9/20           | 59.0 | 77.5 | 60.9 | 77.5 | 55.6 | 77.5 | 55.6 | 77.5 |
| CP 10/20          | 55.9 | 76.0 | 57.8 | 76.0 | 52.5 | 76.0 | 52.5 | 76.0 |
At the 20th floor level (altitude of 65 m), the sound levels at the fencing structures are less than at the level of the second floor, however, significant sound levels exceeding on the sides facing the railway and the ends of the buildings. The maximum exceeding is 5.4 dB\(A\) and 12 dB\(A\) for equivalent levels during the day and at night near Building A. Excess at Building B is 5.1 dB\(A\) and 11.7 dB\(A\).

The increase in traffic intensity of suburban trains predicted for the prospective time period in the daytime period will lead to an increase in the excess of equivalent sound levels in the daytime by 1.9 dB\(A\) at all points.

4. Evaluation of the required sound insulation of facades

In accordance with SP 276.1325800 [5], the assessment of the required sound insulation of facades for normalized premises from the noise of traffic flows is carried out according to the equation:

\[ \Delta L_{\text{req}}(CP) = L_{\text{lim}}(CP) - L_{\text{aper.room}} \]

where \( \Delta L_{\text{req}}(CP) \) is the required decrease in the sound level of the traffic flow noise by the building facade for the considered calculation point, dB\(A\); \( L_{\text{lim}}(CP) \) is the upper limit of the confidence interval for the sound level of the traffic flow at the calculated point (2 m from the facade of the building opposite the room being protected from noise), dB\(A\); \( L_{\text{aper.room}} \) is the permissible sound level in the protected room, dB\(A\).

Evaluation is performed for equivalent and maximum sound levels for day and night time. From the values of the required reduction in sound levels inside normalized premises, the most value is chosen which is used to develop measures to protect the premises from traffic noise.

The calculation was performed for all calculated points for the current and perspective periods of time, using the data in Tables 3 and 4. As the \( L_{\text{aper.room}} \), it is taken 45 dB\(A\) and 35 dB\(A\) for the equivalent sound level for day and night and 15 dB more for the maximum sound level.

The highest values of the required sound insulation were obtained for night-time for facades facing the railway and ranged from 23.3 dB\(A\) to 35.2 dB\(A\). In accordance with these data, it is necessary to select noise protection windows.

In terms of sound insulation, window units are divided into the following classes for reducing the airborne noise of urban traffic [10]:
- class A - noise reduction more then 36 dB\(A\);
- class B - with noise reduction 34-36 dB\(A\);
- class B - with noise reduction 31-33 dB\(A\);
- class G - with noise reduction of 28-30 dB\(A\);
- class D - with noise reduction of 25-27 dB\(A\).

In accordance with the established range of the required sound insulation of facades, window blocks of all classes can be used, depending on the facade of buildings and the height of the apartments. The performed calculated estimation allows recommending installation on the facades of the designed object, facing the railway, the following soundproofing window blocks:
- for the north-east and south-east facades of building “A” - window blocks of class “A”;
- for the south-east facade of building “B” - window blocks of class “B”;
- for the south-west facade of building “A” and the north-eastern facade of building “B” - window blocks of class “B”;
- for the south-west facade of building “B” - window blocks of class “G”.

In accordance with the data of work [11], a window with a glass unit SPO 8ZI-15-13 SMZK (manufacturer of Baswell group, Serbia) can be recommended to ensure the maximum required sound insulation. The airborne sound insulation index of such a glass unit is \( R_w = 42 \) dB according to the results of the measurement in the measuring chambers of the NIISF RAACS and, taking into account the spectral adaptation term \( C \) according to GOST R 56769 [12], gives a sound insulation rating for railway noise \( L_A = R_w + C = 42 + (-2) = 40 \) dB\(A\).
In addition, in accordance with Annex A of the SP 353.1325800 [13, 14], it is possible to use a heat and sound insulation window of ORSP 21-15 (two-chamber double-glazed window) with a 2-knee air change valve, glazing 4 + 16 + 4 + 116 + 1x4 (the valve is closed with flaps) or glazing 4 + 16 + 4 + 116 + 2x4, giving a reduction in traffic noise of 37 dB(A), 39 dB(A) in the closed and 36 dB(A), in the open position.

5. Conclusions
Comparison of the calculated values of sound levels near the studied section of the railway with the results of field measurements made it possible to use the noise characteristics of train flows calculated by the methods of GOST 33325 and SP 276.1325800 to predict noise levels.

The predicted estimation of the noise levels generated in the apartments of the designed multifunctional hotel complex by the train flows of the section of the connecting branch of JSC “Russian Railways” made it possible to determine the required noise reduction by the facades of the buildings of the complex and to propose noise-insulating window units to ensure compliance with noise standards in the apartments.

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