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METHOD OF RAILWAY TRAINS VIBRATION CHARACTERISTIC DETERMINATION BASED ON FIELD MEASUREMENTS

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***Abstract**: The rail transport (railway lines, shallow subway lines or passing on the surface) is a source of increased vibration.As a result, predicting the parameters of vibration and the structure-borne noise generated by it when designing residential and public buildings near lines or designing new transport lines is an important task. For operating lines, the initial data for the forecast are the results of measurements of vibration parameters at the location of the projected building. For projected lines, the parameters characterizing the source of vibration - the vibration characteristics of moving trains - should be used as the initial data for the forecast. The method for railway trains vibration characteristics determination is described which based on field measurements. As an example of the method application determination of vibration characteristics of commuter trains running along the line of the Savelovsky direction of the Moscow railway is sited. Linear regressions equations are given that connect the weighted vibration velocities in the horizontal direction of vibration propagation perpendicular to the railway line with the train speed.*

Keywords: *vibration, commuter train, vibration characteristic, identification, measuring, determining*

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1. INTRODUCTION

The transport infrastructure of large cities and megacities is impossible without the presence of rail passenger transport, which allows for intensive passenger transportation.

It is known that rail transport (railway lines, underground lines of shallow laying or passing on the surface) is a source of increased vibration, which spreads through the ground and is transmitted to the foundations of residential and public buildings located in the technical area of the line. This oscillatory effect then propagates through the load-bearing structures of the building and causes vibration of the walls and floors, which affects the conditions of people staying in them [1-5]. The vibration generated in the premises of residential and public buildings from the movement of trains has a non-constant intermittent character with a pronounced predominance of the signal in the frequency band 1-250 Hz [1, 6] and repeats with a period determined by the train schedule. At the same time, when assessing the vibration impact on people from train traffic, a narrower range of octave bands with central frequencies (f_c) of 4 – 63 Hz is considered [7, 8] using the equivalent frequency weighted vibration velocity (acceleration for public buildings) as the main normalized parameter [9-11].

The regulatory documents in force on the territory of the Russian Federation [9, 10, 12] establish the permissible values of vibration and noise levels in the premises of residential and public buildings.This requires forecasting the vibration parameters and the structural noise generated by it in buildings designed near the lines for the purpose of hygienic assessment of the compliance of the predicted values with the normative values and, if necessary, the development of measures to reduce vibration [7, 8]. At the same time, for existing lines the initial data for the forecast are the results of vibration parameters measurements at the location of the projected building or on the construction site, such measurements cannot be performed for the projected lines and the vibration parameters near the line are used as the initial data for the forecast [7, 13, 14]. In [15] introduced the concept of the vibration characteristics of the train as the intrinsic characteristics of the vibration source (in accordance with terminology of GOST 12.1.012 [16]) as the value of vibration velocity $\boldsymbol{v}(\boldsymbol{r}_0)$ at the reference distance $\boldsymbol{r}_0$ from the axis of the nearest track, taken as the site of action of the equivalent linear source of vibration from passing trains. The paper also defines the criteria for selecting the value of $\boldsymbol{r}_0$ from the independence condition $\boldsymbol{v}(\boldsymbol{r}_0)$ from the damping properties of the ground at a distance of $\boldsymbol{r}_0$ and it is shown that the maximum value of $\boldsymbol{r}_0$ must be assumed to be 1 m to meet this condition in the entire frequency range under consideration. Since performing direct measurements of $\boldsymbol{v}$ ($\boldsymbol{r}_0$=**1 m**) is a complex task, this paper considers a method for determining this parameter from full-scale measurements of the vibration velocity at a suitable distance from the transport line.

2. TRAIN VIBRATION CHARACTERISTIC DETERMINATION BASED ON FIELD MEASUREMENTS RESULTS

2.1.Method for vibration characteristic determination

The vibration characteristic of a moving train is its own characteristic, depending on the category of the train according to SP 441.1325800 [7] and the speed of its movement. The parameters of the vibration characteristic are determined at the reference distance r_0 from the axis of the nearest track [15]. As a result, the value of the vibration velocity at an arbitrary distance r can be determined using the expression [7, 13, 14]:

$$v(r) = v(r_0) \cdot \boldsymbol{C} \cdot \boldsymbol{D} \quad (1)$$

Where
C is the coefficient of geometric vibration attenuation during propagation in the ground;
D is the coefficient of damping of the soil material.

The values of the ***C*** and ***D*** coefficients are estimated by the following equations [7, 13, 14]:

$$\boldsymbol{C} = \left(\frac{r_0}{r}\right)^{0,25} \quad (2)$$

$$\boldsymbol{D} = e^{-2\rho\pi f_c (r - r_0)} \quad (3)$$

Where
ρ = η/c is the parameter determined by [7] (Table 5.4) or calculated based on the results of dynamic tests of the soil, s/m;
η =δ/π is the coefficient of soil loss;
δ is the logarithmic decrement of vibrations; c is the velocity of the longitudinal wave, m/s. (In the set of rules [7], the multiplier 2 in the exponent is mistakenly omitted – see the Standard [14]).

The value of the vibration characteristic is determined from the solution of the inverse problem by measuring the ***v(r)*** values and calculating $v(r_0)$ from the equation (1). The calculation should be performed in octave frequency bands in view of the frequency dependence of the damping coefficient ***D*** of the soil material.

2.2. Example of determining vibration characteristics

As an example illustrating the application of the method, let us consider the determination of the vibration characteristics of suburban trains running on the line of the Savelovsky direction of the Moscow Railway. Vibration measurements from trains were carried out at two points (P1 and P2) located on a straight two-track section near the Degunino station. The distances from the measurement points to the middle of the near and far track were r_n = 6 m, r_f = 11 m for ***P1*** and r_n = 4 m, r_f = 8 m for P2. The choice of the measurement section is related to the fact that there is a significant variation in train speeds, since some trains have a stop at the station, and some (mainly „Aeroexpress" trains) pass it without stopping. The distance between the measurement points was 70 m. The vibration velocity was measured using the ZET048-Cseismic recorder simultaneously in three directions: the ***Z*** axis is vertical, the ***X*** axis is perpendicular, and the ***Y*** axis is parallel to the railway line. The measured parameters were the maximum and equivalent values of the vibration velocity in the octave bands of the normalized frequency range. The measurements were performed according to the procedure corresponding to the requirements of SP 441.1325800 [7]. In total, vibration parameters were measured for 87 electric trains passing in two directions along the far and near tracks to the measurement points.

The values of the vibration characteristic $V(r_0=1m)$ at the octave bands with the central frequencies f_c = 4 – 125 Hz were calculated using equations (1) – (3), substituting in them the measured values of the vibration velocity $v(r_n)$ and $v(r_f)$ and the corresponding values r_n, r_f.

Since the calculated values of the vibration velocity correspond to a single distance r_0 = 1 from the middle of the track along which the train is moving, they can be considered as a single array for each direction. To determine the trend of vibration velocity changes with increasing train speed, an array of 87 elements in each octave band was divided into four arrays: three of 22 elements and one of 21 elements, including consecutive values of vibration velocity, arranged in ascending order of train speed. For each array, the average values of vibration characteristics in the octave frequency bands and the corresponding values of train speeds are calculated. The frequency weighted values of vibration velocity $v_{w,max}$ and $v_{w,eq}$ were calculated from the vibration velocity values v_{max} and v_{eq} in octave frequency bands using frequency weighting in accordance with [7, 9]. The calculation results for the ***X*** direction are shown in Tab. 1.

Train speed, km/h	Vibration velocity of 10^{-6}, m/s, in the octave band with the mean geometric frequency, Hz												Frequency weighted value, m/s	
	4		8		16		31,5		63		125			
	max	eq	max	eq	max	eq	max	eq	max	eq	max	eq	max	eq
36,9	122,7	72,1	176,6	104,9	478,1	319,9	1305,6	891,4	463,8	324,1	663,0	439,6	1622,9	1100,6
41,1	174,8	101,5	248,1	150,0	479,1	339,5	1407,3	977,4	499,5	351,8	720,7	463,6	1752,4	1200,9
46,2	183,4	110,8	269,8	176,9	504,9	343,5	1517,4	1028,6	536,0	377,5	720,8	478,4	1863,0	1261,3
56,3	215,3	126,4	500,3	307,9	519,2	361,9	1576,8	1075,2	544,0	391,0	769,9	526,4	2018,2	1352,0

Table 1. Average values of vibration characteristics and train speeds

The tendency of increasing vibration velocity with increasing train speed is visible. This allows us to obtain regression dependences of vibration characteristics on the speed V_{tr} of the train movement. The linear regression equations obtained for the frequency weighted vibration velocities are given below [17]:

$$v_{w,max} = 19{,}8V_{tr} + 921 \quad (4)$$

$$v_{w,eq} = 12{,}3V_{tr} + 674{,}3 \quad (5)$$

The values of the correlation coefficient for the obtained equations are 0.99 and 0.97, respectively, which indicates a fairly good linear relationship between the considered values.

3. CONCLUSIONS

The vibration characteristics of trains in the form of equivalent and maximum values of vibration velocity at the distance of r_0 = 1 m from the middle of the train path can be determined from the results of full-scale vibration measurements.

The trend of increasing the vibration velocity with increasing the speed of suburban train allows us to obtain the corresponding dependences of linear regression.

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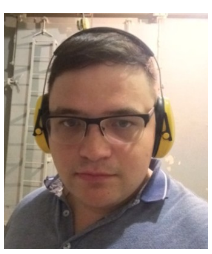

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