Vibration Characteristics of Railway Trains

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Abstract. The problem of predicting vibration on the territory of residential buildings adjacent to the projected lines of rail transport is considered. The concept of vibration characteristics of trains is introduced as an intrinsic characteristic of a vibration source, the knowledge of which is necessary to predict vibration parameters in an area of impact of lines. The substantiation is given for choosing the equivalent and maximum value of vibration velocity as the parameter of the vibration characteristic. For four generalized types of soils, the values of the maximum distance from the middle of the nearest track were obtained for the experimental determination of the vibration characteristics of a passing train. The assessment was carried out in the frequency range inherent in the vibration generated by rail transport on the basis of the insignificance of the influence of the soil parameters on the values of the vibration characteristics. This makes it possible to determine the values of vibration characteristics irrespective of the type of track structure and to consider the obtained value as an intrinsic characteristic of trains, which depends only on the parameters of their movement.

1. Introduction

It is known that rail transport is a source of increased vibration in the premises of residential and public buildings located in the area of its impact [1-5]. In this case, the generated vibration has a non-constant intermittent character in time, depending on the train schedule. The frequency range of vibration and the structure-borne noise generated by it is quite wide and covers octave bands with central frequencies from 4 to 250 Hz [1, 6]. In this regard, there is specificity in the regulation of vibration affecting a person and certain problems arise in its assessment [7, 8].

The task of predicting the vibration levels generated in the buildings projected near the lines and, if necessary, the development of effective measures to reduce vibration is urgent. For operating lines, the initial data for the forecast are the results of measurements of vibration parameters at the location of the projected building or at the construction site. For the projected new lines, such measurements cannot be performed and the parameters characterizing the line as a vibration source - its vibration characteristics should be used as the initial data for the forecast. In this work, the concept of vibration characteristics of a train or a section of a railway line is introduced, and criteria for their experimental determination are derived.
2. The concept of vibration characteristic

In general terms, the concept of vibration characteristic of a vibration source or vibration-isolating product was introduced in the Interstate Standard GOST 12.1.012-2008 [9] as a quantitative indicator reflecting the ability of a product to produce or transmit vibration and is established during product type tests in accordance with the vibration test code. In this sense, the vibration characteristic is applied mainly to stationary sources of vibration, for example, hand-held and hand-operated machines [10].

As applied to railway transport, such parameters are the values of vibration velocity $v(r_0)$ or vibration acceleration $a(r_0)$, determined at a reference distance $r_0$ from the axis of the nearest railway track, taken as the site of action of an equivalent linear source of vibration generated by a passing train [11-13]. The reasons for choosing vibration velocity as the estimated parameter of the vibration characteristic are the following circumstances [14]: permissible values of vibration velocity for the frequency spectrum with a predominance of vibration from rail transport (octave bands with the central frequencies of 31.5 - 63 Hz) correspond to the values established in the sanitary regulations [15] for the frequency weighted value; the frequency weighting factors for the spectral bands of the vibration signal to be estimated are 1; the level of sound pressure of structure-borne noise in the room is determined by the values of the vibration velocity of the enclosing surfaces oscillations of the room. In addition, German experts have established and reflected in the Standard [16] that human perception of vibration is proportional to the magnitude of the vibration velocity.

In this case, the value of the vibration velocity $v(r)$ at an arbitrary distance $r$ from the line can be determined using the equation [17-19]:

$$v(r) = v(r_0) \cdot C \cdot D,$$

where $C$ is the coefficient of geometric vibration attenuation during propagation in the soil; $D$ is the damping coefficient of the soil material. Parameters $C$ and $D$ are estimated by the following dependencies [18] (Appendix B):

$$C = \left( \frac{r_0}{r} \right)^n$$

$$D = \exp(-2\rho\pi f_c (r - r_0)),$$

where $n$ is the coefficient selected depending on the type of wave propagation mechanism; $f_c$ is the central frequency of the octave band, Hz; $\rho = \eta/c$ is the parameter selected according to Table 1 or calculated based on the results of dynamic soil tests according to Standard [18], s/m; $\eta = \delta \pi$ is the soil loss coefficient; $\delta$ is the logarithmic decrement of fluctuations; $c$ is the longitudinal wave speed, m/s.

3. Vibration characteristic of a train

The vibration characteristic of a moving train is its own characteristic, depending on the category of the train according to [19], its length and speed of movement. The parameter of the vibration characteristic is determined at the reference distance $r_0$ from the axis of the short track. The value of $r_0$ should be selected from the condition that the value of the vibration characteristic is independent of soil properties, in particular, from the damping coefficient of the soil material at the distance $r_0$.

The set of rules [19] noted that the difference in soil properties can be considered insignificant if it does not exceed 10-15%. Applying the 15% limitation to the value of $D$, from equation (3), one can obtain the following criterion for choosing the maximum value of the distance $r_0$ for simulating a train with an equivalent linear vibration source acting on the axis of the short track:

$$r_0 \leq \frac{\ln0.85}{2\rho\pi f_c} .$$


Table 1. The values of $\rho$ depending on the type of soil according to [20].

| Soil type | Description | $\rho$, s/m |
|-----------|-------------|-------------|
| 1         | Dispersed incoherent, incl. technogenic soils: | $2 \cdot 10^{-4} \div 6 \cdot 10^{-4}$ |
|           | - loess soils |             |
|           | - hot soils   |             |
|           | - river sand  |             |
|           | - dune sand   |             |
|           | - organic soils |         |
|           | - surface soil layer | |
| 2         | Dispersed disconnected and cohesive sedimentary and eluvial soils: | $6 \cdot 10^{-5} \div 2 \cdot 10^{-4}$ |
|           | - sands;      |             |
|           | - sandy loams, loams; |         |
|           | - silty clays; |             |
|           | - gravel, crushed stone; |      |
|           | - dusty sands, silt |         |
| 3         | Dispersed and rocky soils: | $6 \cdot 10^{-6} \div 6 \cdot 10^{-5}$ |
|           | - dense sandstone; |             |
|           | - dry compacted clay; |          |
|           | - compacted boulder moraine, glacial tillites | |
| 4         | Rocky soils: | $< 6 \cdot 10^{-6}$ |
|           | - rock, continental soil; |        |
|           | - rock        |             |

The calculated values of $r_0$ for four types of soil from Table 1 and the octave bands of the frequency range inherent in the vibration of rail transport are given in Table 2.

Table 2. Reference distance limits $r_0$

| Soil type | $\rho$, s/m | $r_0$, m, in octave band with central frequency, Hz |
|-----------|-------------|---------------------------------------------------|
| 1         | $6 \cdot 10^{-4}$ | 10, 8, 5, 4, 2, 7, 1, 4, 0, 7, 0, 3, 0, 2 |
| 1, 2      | $2 \cdot 10^{-4}$ | 32, 3, 16, 2, 8, 1, 4, 2, 1, 1, 1, 0, 5 |
| 2, 3      | $6 \cdot 10^{-5}$ | 215, 6, 107, 8, 53, 9, 27, 4, 13, 7, 6, 9, 3, 4 |
| 3, 4      | $6 \cdot 10^{-6}$ | 1077, 8, 538, 9, 269, 4, 136, 9, 68, 4, 34, 5, 17, 2 |

Only for soil of types 3 and 4 were the distances obtained that can be implemented in practice to measure the vibration characteristics of trains in the entire frequency range inherent in the vibration generated by trains. If the upper and lower track structures are dominated by soft materials with high vibration energy losses, so that the soil must be classified as type 1 or 2, the vibration characteristic of trains can only be measured in a truncated frequency range. In this case, the absorbing properties of the soil have a noticeable effect, and the value of the vibration parameter to be measured should be considered as the vibration characteristic of the section of the line on which the measurements were made.

In this case, when predicting the vibration effect, the value of $v(r_0)$ included in equation (1) must be corrected by a factor $D/D_0$, where $D$ is the damping coefficient of the soil material of the line section for which the forecast is performed and $D_0$ is the damping coefficient of the soil material of the line section where $v(r_0)$ was determined.
4. Conclusions

Vibration characteristics of trains or a section of the railroad line allow predicting the vibration impact from a projected or constructed rail transport line.

When experimentally determining the vibration characteristic of a train, one should take into account the absorbing properties of the soil included in the upper and lower track structure. The values of the vibration parameter measured at a distance exceeding 3 m from the axis of the short track should be taken as the vibration characteristic of the train and can be used in the forecast only in the case of weakly sound absorbing materials of soils that are part of the upper and lower track structure. In other cases, the measured value should be taken as the vibration characteristic of the line section and must be corrected taking into account the damping factors of the soil material.

5. References

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