603. The Dynamic Effect of the Moving Trains on the Railroad Rails and Propagation of Excited Vibrations

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(Received 12 November 2010; accepted 9 December 2010)

Abstract. The report deals with the opportunities for the implementation of the EU "Rail Baltica" study project, evaluating the fulfillment of acoustical requirements for the railway route. The paper considers the causes of excited vibrations and noise. The railway has always been one of the most important transport means, which ensures the quality of the rail freight. Propagation of vibrations, excited by the moving train, to the environment and their evaluation is significant problem. Conducted research work will be used in laying out the new railroad line from the West to Central Europe. It will provide the possibility to improve the quality of the railroad route as well as reduce vibrations and noise generated by the trains. It was established that the transport moving along the railways caused many serious problems from the ecological point of view, noise and vibration being among the most important issues. Heavy train moves along the metal railway on its metal wheels i.e. rolling-stocks. This is one of key sources of noise and vibration: it produces audible low-frequency noise as well as non-audible noise - infrasound. The influence of the infrasound on the environment and human health has not been thoroughly investigated, yet there are plenty of means for reducing it. The research performed in this area indicates many cases when infrasound is far more harmful in comparison to the audible sounds. It is a costly and complicated process to eliminate infrasound from the aforementioned sources therefore the companies and private owners, as well as state institutions do not adopt relevant measures to solve this problem. Moreover, the audible sound would also decrease in such a case. In the paper the author treats the problem on the basis of practical tests and research conducted by different scientists as well as proposes approaches for solution of the considered problem.

Key words: Vibration propagation, train noise, vibration reduction.

Introduction

Let's study the issues related to the impact of dynamic actions, excited by the movement of the train (transport). Dynamic loads, induced during the movement of transport, excite the vibrations of the rails. The latter, in their turn, become the sources of shocks, which propagate over the considerable distances through the ground. Vibrations by their way of propagation are transmitted to the surrounding buildings and structures.

Shocks of the ground, conditioned by the movement of trains, as a result of prolonged action, may cause the subsidence of foundations and vibro-fluidity of dispersing grounds. Due to prolonged action of shocks and increasing acceleration of vibrations, the resistance to displacement of dispersing grounds, especially *cohesionless,* is decreasing significantly, and the change in the coefficient of porosity of the grounds with the increase of vibrations is augmenting, conditioning the vibrocompaction of grounds.

Dynamic Actions and Properties of Grounds

Dynamic properties of grounds depend on the type of dynamic actions. The main characteristics of dynamic properties of grounds are characteristics of elastic and absorbing properties at dynamic loads of low intensity (not exceeding the limit of elasticity) – module of elasticity *E*, Poisson's coefficient μ, coefficient of attenuation of vibrations *n*, as well as other equivalent dynamic characteristics, for instance, velocity of propagation and coefficient of absorption of elastic waves.

Theoretical investigations of wave processes, activated in the ground during movement of trains, are based on the study (*of estimated schemes of models*), exploring in general the properties of the ground with some approximation to the natural ones and permitting their satisfactory description mathematically [1].

Models of the grounds are constructed on the basis of the generalized quantitative results of macroscopic trials on the compaction and discharge of the ground, for the estimation of wave parameters, residual deformations, etc. [2]. Elementary microscopic correlations in the particles of the ground hence are estimated in terms of quality. Nevertheless, their analysis makes it possible to construct the models of the ground. The grounds are studied dynamically as the continuous media, filling the space continuously.

Propagation of waves in the isotropic ideally elastic medium is described by the following differential equations [3]:

$$\nabla^2 u - c^2 \frac{\partial^2 u}{\partial t^2} = 0;$$
$$\nabla^2 \upsilon - c^2 \frac{\partial^2 \upsilon}{\partial t^2} = 0;$$
$$\nabla^2 \omega - c^2 \frac{\partial^2 \varpi}{\partial t^2} = 0. \qquad (1)$$

It may be demonstrated that the elastic wave essentially represents two independently propagating waves. In one wave, the displacement is directed along the propagation of the wave itself (*longitudinal* with the velocity c_1); in another wave, the displacement takes place in the plane, perpendicular to the direction of propagation (*transversal* with the velocity c_2).

In the formulae (1), the following designations are accepted: $c=c_1$ or c_2 is the velocity of propagation of elastic waves.

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$ - is the Laplace operator;

u υ and ω are the constituents of elastic displacements in the longitudinal or transversal wave in the direction of axes *X*, *Y* and *Z*.

It may be demonstrated that velocity of *longitudinal* elastic waves is:

$$c_1 = \sqrt{\frac{L + 2M}{\rho}}, \qquad (2)$$

where *L* and *M* are the Lame constants, connected to the module of normal elasticity E and the coefficient f transversal elasticity μ by means of dependences:

$$L = \frac{\mu}{(1+\mu)(1-2\mu)}; \quad M = \frac{1}{2(1+\mu)}E; \tag{3}$$

$\rho = \gamma / g$ = compaction of the medium (γ is the volume weight; g - acceleration of the force of gravity).

Velocity of the propagation of transversal waves (waves of distortion) equals:

$$c_2 = \sqrt{\frac{M}{\rho}} = \sqrt{\frac{E}{2(1+\mu)\rho}}. \tag{4}$$

Value c_2 is connected with the value c_1 through the following dependence:

$$c_1 = c_2\sqrt{\frac{2(1-\mu)}{1-2\mu}}. \tag{5}$$

Expression (2) indicates that always $c_1 > c_2$, i.e. longitudinal waves, are propagating in the continuous elastic medium with the higher velocity as compared to the transversal ones. If to apply the formulated dependences to the grounds, then, for example, for clays $\mu = 0,4$, we shall obtain that the longitudinal waves are propagating 2.45 times quicker than the transversal ones, and for sand (at μ = 0,2) – approximately 1.63 times. The results of direct measurements of velocity of propagation of vibrations reveal that this correlation for other grounds is significantly higher.

Particularly significant are the waves that are induced by the sources of vibrations - trains that are located relatively close to the surface of the ground (the rails of the road). Maximum amplitudes of displacements in such waves are observed close to the source of vibrations, but at some distance from it they are so low so that no account may be taken of them at all. The velocity of propagation of surface waves c_3 is somewhat lower than the velocity of transversal waves. Thus, at μ = 0,25 , the volume $c_3 \approx 0{,}92c_2$ and at μ = 0,5, approximately $0{,}95c_2$. For determination of amplitudes of surface waves at comparatively large distances from the source of vibrations, the following formula may be used [4]:

$$A_r = A_0\sqrt{\frac{r_0}{r}}e^{-\alpha(r-r_0)}, \tag{6}$$

where A_r and A_0 are the amplitudes of vibrations in the ground at a distance r and r_0 from the source; ά is the coefficient of attenuation of vibrations, m^{-1} or cm^{-1}.

Experimental Model

The results of experimental study of changes of amplitudes of surface waves in respect to depth are of substantial significance. Thus, it was revealed that at small depths, not exceeding 0.2–0.3 of the wave length, the amplitudes of vibrations are reduced relatively insignificantly.

The diagram (Fig. 1) depicts the character of attenuation of surface waves in terms of depth, which is produced according to the data of measuring of vertical vibrations, resulting from the experimental machine. It should be taken into consideration that the character of the change of amplitudes with a depth at the direct proximity to the foundation (the source of waves 0 will be somewhat different (Fig. 1b).

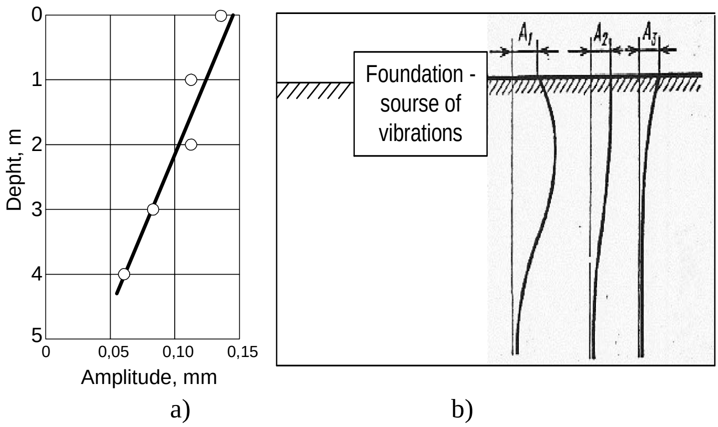

Fig. 1. Change in the amplitudes of vibrations of the ground under the foundation (a) and at a different distance from it (b)

Experimental investigation of vibration propagation through the ground

Experiment was performed in the specific object. In order to investigate the impact of vibrations on the environment, it is necessary to study the parameters of vibrations that propagate through the ground in the environment under study. This information is also necessary for investigation of generation of vibrations in the residential premises and for determining measures for vibration reduction.

Vibration values are measured using vibration measuring systems, which consist of a sensor, amplifier, filters and indication device. Vibrations were measured in the intervals of standard octaves, by means of the vibration meter 2511.

Experimental measurements of vibrations were carried out in the premises and territory of a private company (Fig. 2).

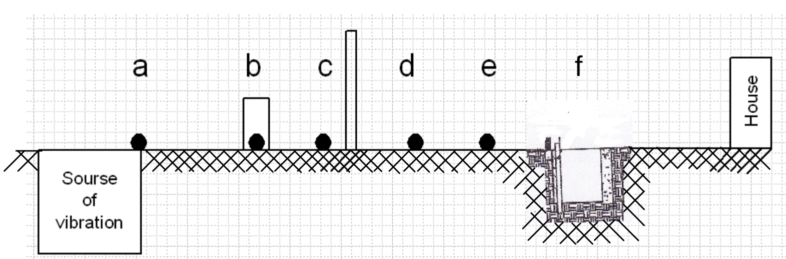

Fig. 2. Layout of measurement points and vibroinsulation joint. a – vibromachine base; b – operator's booth; c – inside near the external wall; d – outside; e – at a distance of 100 m from the vibration source; f - vibroinsulation joint

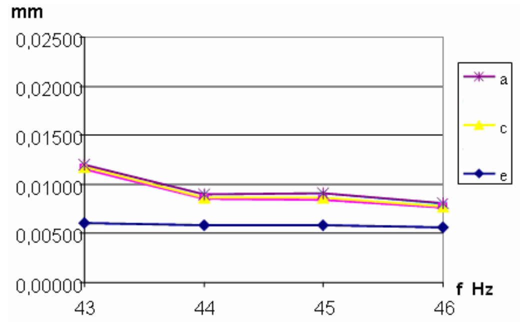

Fig. 3. Amplitudes of vibrations during the free running of work

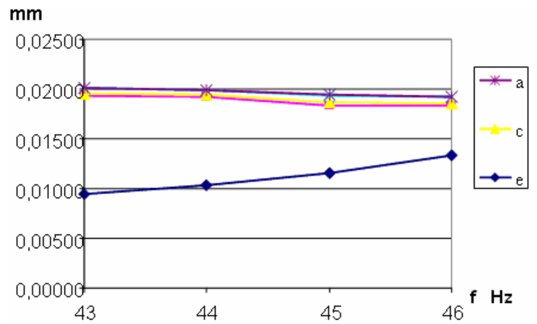

Fig. 4. Amplitudes of vibrations during the work

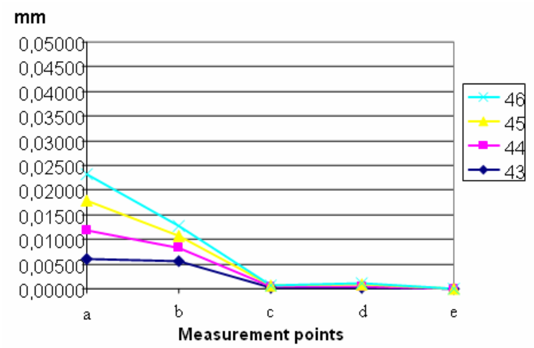

Fig. 5. Amplitudes of vibrations further from the source of vibrations during the free running of work

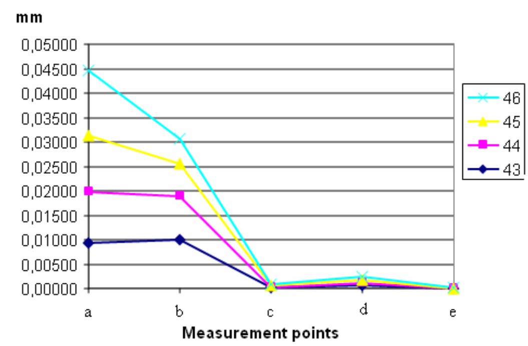

Fig. 6. Amplitudes of vibrations further from the source of vibrations during the work

Graphical dependences (Figs. 3-6) indicate that vibrations emitting along the ground surface abruptly diminish at the outside of premises, though vibrations emitting along deep layers of the ground reach the foundations of dwelling buildings. It is possible to confirm this on the basis of theoretical considerations.

Further away from the vibration source, the value of parameters of the generated vibration reduces, e.g., the measured amplitudes of vibrations on the foundation and outside the building (on the ground at a distance of 100 m). Amplitudes of vibrations decrease from 0.05 to 0.025 mm, and at 100 m away, vibrations reduce to the values of 0.004 m/s^2. However, these vibrations, upon reaching the foundations of the residential buildings, are transmitted to their walls and transformed into the sound (infrasound). After the performance of measurements in the premises (bedroom) of the residential house, vibrations of the frequency of 10-12 Hz and the sound (infrasound) of the corresponding frequency were registered.

Approaches for vibration reduction

There are many methods and approaches for reduction of intensity of vibration parameters. They are applied taking into consideration a type of the source of vibrations, its specifications and destination. For reduction of intensity of the parameters of source of vibrations under study, it is possible to apply the following methods. Namely, reduction of vibrations at the source of their onset, on the way of propagation, and increasing the distance from the source and the object protected from the impact of vibrations. Let us describe in brief the essence of these methods and the opportunities for their application in our case study.

However, it is necessary to state that the aforementioned as well as other unmentioned approaches for reduction of vibrations are not always applicable. In the case of our study, a vibromachine must excite the vibrations of the required intensity of the working part of the mechanism, which are necessary for the fulfillment of the preset working process. Therefore in this case attention shall be concentrated on the bearing part, where the vibrating mechanism is fixed by way of damping and insulation.

For reduction of transmission of vibrations through the ground, a vibroinsulation joint was installed (Fig. 2), which channel was filled with expanded-clay granules (Fig. 2). After the implementation of that measure, no vibrations and outside sounds were registered inside the residential house.

Conclusions

The paper presents the analysis of railway-induced vibrations and noise excitation sources. It was determined that due to train movement, because of various reasons, the excited vibrations are transferred to the ground through the metal railing and its fastening equipment.

The conducted analytical analysis of vibration propagation through the ground demonstrates that low-frequency vibrations propagate fairly far away. This is one of the important reasons for a negative impact and anxiety that is experienced by the inhabitants that reside near the railway lines.

Investigation of vibrations transmitted to the environment revealed that surface waves of vibrations propagate far with a certain gradual attenuation, but depending on the power of the source of vibrations, they remain harmful and are capable of exciting low-frequency vibrations of the structures of buildings and generate the corresponding sound.

The measure, recommended in the work, for insulation of transmission of vibrations, reduced the amplitude of vibrations propagating through the ground resulting in the level of impact, which is not harmful to the environment and people.

 DECEMBER 2010. VOLUME 12, ISSUE 4. ISSN 1392-8716

On the basis of theoretical and experimental investigations, it is possible to state that with the railway lines passing close to the residential houses it is necessary to install analogous vibroinsulation joints.

While implementing "Rail Baltica" project, in designing the screens for noise reduction, it is necessary to foresee the places where it would be necessary to implement our recommended measures for insulation of vibrations, adjusting their installation together with the foundations of noise screens.

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