

604. Noise in european railway under modernization and its reduction

Dr. D. Gužas¹, V. Tričys²

Šiauliai University,
Vilnius str. 88, Šiauliai, LT-76285, Lithuania

e-mail: danielius.guzas@gmail.com¹

(Received 4 November 2010; accepted 9 December 2010)

Abstract. This research work presents various noise reduction measures, which, taking into account the relief of the country and the location of urban areas, should be designed during modernization of railway lines. European project “Silence” is dedicated to the reduction of railway noise in urban areas. Attention in this paper is devoted to the impact of infrasound on the people living near the railway. Here we present the study of propagation of vibrations through the ground to the residential buildings. With this aim in view, experimental tests were performed for clarification of vibration propagation process from the railway lines (railings) to the residential building. Evaluation of possible impact of noise caused by the trains on the environment is presented. The report provides sound pressure levels from the moving trains, which will run until the reconstruction of the main line. Moreover, noise levels are predicted when modernizing road and railway transport means (locomotives, vans, etc.). This research work studies spectrum composition of noise produced by the train in terms of quantity and quality of the radiated energy with respect to the human body, i.e. not only by the sound level dBA, but also by the spectrum composition of sound pressure level. Attention is focused on the impact of very low sound frequencies and infrasound. On the basis of the measured and calculated noise levels propagated by various future railway trains, the impact of noise produced by the trains on the environment is specified. Based on the results of noise analysis, measures are foreseen for the reduction of harmful noise propagated by the trains. The article presents the research on reduction of noise and vibrations by means of barriers theory and their implementation in practice. Acoustic barriers are divided according to their usage and structures. The article deals with the presentation of implementation of screens in practice together with their theoretical evaluation as well as dependences on structure and materials of the screens. Evaluation of their positive and negative acoustic properties is provided as well. The obtained results will be used in the recommendations when designing noise reduction measures and expanding a railway network in the Baltic countries.

Key words: Railway noise, noise reduction.

Introduction

In geographical terms the territory of Lithuania and other Baltic states is convenient for transit cargo transportations in the East–West and South–North directions. Therefore, after entering the European Union (EU), the necessity arose for Lithuania and other Baltic states – Latvia and Estonia to integrate into the European railway system, adapting railway infrastructure to the level of the European Union countries. For that purpose, a strategic project

of North–South railway has been developed between Tallinn in Estonia - via Latvia and Lithuania - with Warsaw in Poland (Fig. 1).

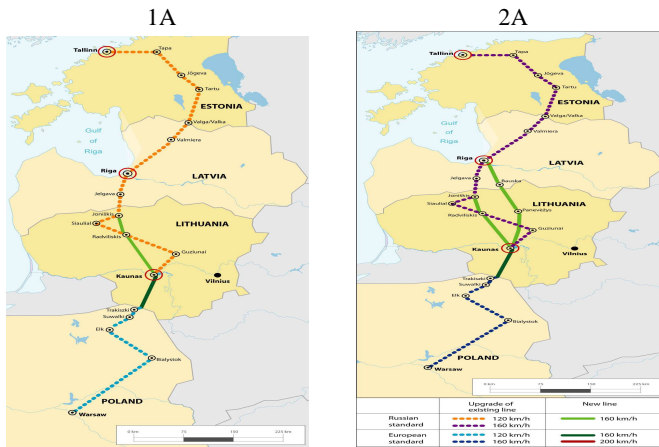


Fig. 1. Graphical representation of the “Rail Baltica” railways: 1A – Graphical presentation of Package 1; 2A - Graphical presentation of Package 2

Despite the fact that “Rail Baltica” is one of the TEN-T priority projects, it has become clear that very little specific planning and analysis has been made for the project in the countries [1,2].

Our performed analysis allows one to state that Lithuanian railway lines are not of appropriate quality and therefore noise level near the passing railway lines is fairly high and reaches 100 dB(A) and more (Figs. 2-3).

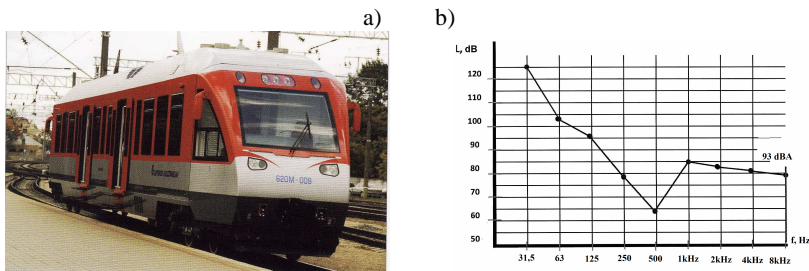


Fig. 2. The locomotive and the locomotive typical diagram of sound pressure levels: a – modern locomotive “Siemens”; b – locomotive typical diagram of noise levels

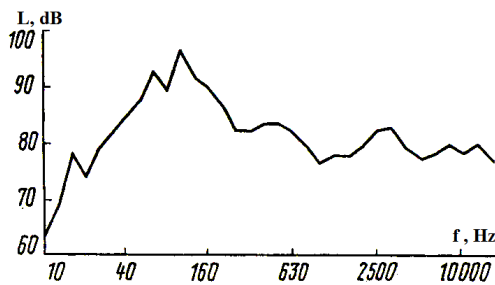


Fig. 3. A typical diagram of sound pressure levels produced by the train

Railway lines, along which various types of trains are moving, have no protecting technical measures against the increased impact of noise (e.g. barriers). Therefore the environmental problems, including those of noise impact, have been foreseen in a strategic study.

A strategic study of the "Rail Baltica" railways has been conducted in the period November 2005 - December 2006 according to the request of the European Commission, Directorate-General Regional Policy. The objective of the pre-feasibility study has been to assess strategically the overall need and potential for developing "Rail Baltica" and to provide recommendations for project implementation of the most suitable development option in terms of alignment, technical standards and organization.

An expert commission, formed by the Railway Cooperation Organization, developed and approved a number of documents, dealing with the train noise measurement, the evaluation of impact on the environment and recommendations for its reduction [3].

The main idea behind "Rail Baltica" is to develop high-quality connections for passenger and freight transport between the Baltic States and Poland, as well as between the Baltic States and other EU countries through the hub Warsaw. Improved rail lines will result in more efficient land-bound connections between the Baltic and the Nordic countries (particularly Finland) and in the long run potentially further to Central Asia. Improved rail links will benefit the environment, contribute to alleviate congestion on the European road network, increase the accessibility of the Baltic States and potentially improve conditions for accelerated regional development in the countries involved.

For the successful implementation of the project, currently, it is necessary to investigate the noise caused by the trains moving along the railways, to identify the reasons of its generation and to foresee the main measures for reduction of noise propagation.

It is understandable that in order to make a step forward, we had to analyze the works already performed by the acoustics scientists working according to the given themes and to take the noise-reduction solutions, complying with the national interests and the existing conditions.

Problem and its solution

Noise in the territory near the main road, propagated into the surrounding space, during the train movement is the most important constituent of the noise of trains. Noise in the territory near the main road depends on different factors, such as the interaction of the rolling stock and the line, vibrations of constructions, speed of the train movement, length of the stock, turbulence of air flows, aerodynamic forces at high speeds (i.e. > 250 km/h), etc.

Alongside the air noise, which is radiated in the surrounding space, structural noise arise and they are excited by dynamic forces at the point of the contact of the wheel and the rail at the movement. Those vibrations are propagating along the upper structure of the line and the bearing constructions, passing over the adjacent to the neighboring buildings. They usually are perceived by man as low-frequency noise. People who live or work close to the main road complain of those negative phenomena.

To reach noise level normative values, for reduction of the effect, it is necessary to perform additional research works and evaluation of the impact of noise on the environment before the start of constructions, the predicted railway noise and vibrations impact and the necessary measures of their reduction at the stage of designing.

In order to reduce the noise transmitted by railway transport, noise screens will be installed. It was designed to implement in the "Rail Baltica" project described by us. Therefore, in this work the major attention will be focused on the use of noise barriers and their elements to reduce the noise transmitted by trains.

Impact of noise on the environment

Increased noise levels were also identified when the train wagons are directed to loading-unloading station. The noise in the marshalling yard and noise in the railway transport production enterprises may be the main in the territory close to the main road in the region of the residential blocks, adjacent to those objects. The main sources of noise are rail tractors and noise from the collision of wagons. The noise level usually in this case exceeds by 20-30 dBA and more the level of the surrounding background. At a distance of 30 m from the axis of the lines, the level of the noise from the collision of wagons constitutes 95–100 dBA.

People, living near the urban area, close to the railway lines, which are located under the viaducts and other road facilities, complain that the generated infrasound from the passing train are felt in the residential houses (Figs. 2-3).

As it is observed from the spectra (Figs. 2-3) of sound pressure level of noise transmitted by trains, the highest sound pressure level is at low frequencies (30-100Hz). Though, in some cases sound frequencies may be within the range of infrasound frequencies.

The impact of infrasound on the individual and living organisms in most cases is negative. It is identified that some low-frequency sounds or infrasound are of negative action: sound at the frequency of 37 Hz causes cardiac, pulmonary and stomach disorders. Due to frequently heard 16 Hz frequency the activity of the stomach becomes disturbed. It is notable that we can feel very low and high sounds, beyond the limit of hearing, with all the body, like mechanical vibrations, heat and the like. Sounds, with the frequency lower than 16 Hz, are harmful to the individual, causing the unjustified fear, anxiety, fatigue, “sea” disease symptoms, and may be harmful to eyesight and become the cause of the serious health disorders. Especially dangerous is infrasound at the frequency of 7 Hz, since this sound, generating frequencies, while being close to the organs of our body, may disturb the heart or brain activity.

Impact of infrasound on the individual.

Infrasound affects people biologically, when its frequency (7-8 Hz) coincides with the alpha rhythms of the brain (flows of certain frequency). The frequency of sounds of 18-19 Hz coincides with the resonance frequency of eyes; therefore it may cause optical illusions. This may be very dangerous when driving the means of railway transport.

When conducting research of the impact of infrasound on the environment, it was established that infrasound waves may cause the feeling of fear and anxiety.

Harmful impact of transport on the environment is related not only to the radiating, audible sound (noise), but also to the vibrations and the accompanying infrasound. Therefore in the project “Rail Baltica” it is foreseen (together with the barriers for reduction of vibration) to implement the measures for noise as well.

Many railway lines were built long ago and not taking into account the noise impact on the environmental territory. Townships and villages, near which the fast railway networks are laid, experiences harm (noise, vibrations and infrasound). For solving this problem the joint efforts of the state, local administration and railway companies are needed. Planning new railway lines according to the project “Rail Baltica”, the optimum railway line design is needed, taking into account a distance from the road to the closest building and the land excavation.

Construction of acoustic barriers and their properties of noise reduction

In practice numerous acoustic barriers of various types against noise are used worldwide. They vary in their purpose and design. They could be subdivided into several groups, namely, screens for noise reductions, screens for vibration damping and vibroacoustic

screens that retain vibration and noise. Their efficiency is predetermined by large number of different requirements.

These are materials with their own properties, dimensions, etc. One of the more important requirements is the vibroacoustic properties of materials. Their possible efficiency is calculated on the basis of vibroacoustic parameters, and preconditions are formed for dimensions and forms of shield constructions. The constructions and forms of screens have a more significant impact on the noise permeability, i.e. its reduction when passing over to the silent side of the screen. In our work [4, 5] the effect of wall rigidity on sound insulation of the acoustic screens was studied. The form of screen elements and the final shield construction as well as screen impedance have an effect on increasing the rigidity. How should an acoustic shield look like as regards its form so as it would have many vibroacoustic properties in reducing noise and vibrations? It is still challenging to precisely answer this question since no single opinion exists on this issue. A good number of other requirements are also set in respect of the form of shield construction. Of those more important are aesthetical issues as well as ecological requirements. Therefore comprehensive work should be carried out in this field aimed at solving all the problems related to acoustic screens. In this paper we will attempt to present the samples for solving those problems.

Our theoretical calculations [4, 5] are based on increasing the rigidity of construction. However, other properties of materials and constructions, like, for example, various resonances, elasticity, etc. also have a great impact. An important requirement set for the screens is the evaluation of the environment where the screen will be used. The environment, specifications of noise propagated in it and vibration sources. Some of those more important would be the spectra of their propagated noise or vibrations, where the location of the values of the power of propagating noise or vibration parameters by frequency would be observed. Therefore this information provides requirements for acoustic screen design. Theoretical fundamental decisions provide ideas how to use theoretical conclusions in some cases.

The paper provides our theoretical justifications carried out for implementation of the proposed measures.

Evaluation of barrier efficiency

The application of barriers for noise reduction has been known since the time the problem has become urgent. In order to avoid noise the first radical attempts were made by isolating in the premises the sources of high intensity noise from the sources radiating lower noise.

The article presents analysis of screens to be applied in reducing the traffic noise. The analyzed source is considered as the noise heard from the railway interfering into the people's activity zone and into the living area. The efficiency of screens could be determined by experimenting or by carrying out calculations. Barrier efficiency could be determined by means of experimental testing in the surrounding environment, namely determining the place it would be placed whether in the laboratory in the field of freely propagating sound, namely under the conditions of free field, in the charged chambers.

However, the best method for evaluation of the screens is to apply both methods, namely, to calculate various variants and to identify the best one following by its testing. In order to select and calculate the required barriers with such efficiency to be able to reduce the level of noise up to the indicated values in the directives, it is required to carry out additional studies with purpose to determine the characteristics of noise intended to be reduced.

With the help of these noise characteristics it is possible to compile noise reduction model and select by means of the calculation method the determined noise reduction means, screens are included here.

That is why, first of all we have to possess theoretical barrier model, the methodology of calculation, which depends on the design of the barriers, i.e. what elements and materials it is compiled and what materials could be applied in designing acoustic barriers. One more component that is very important to be considered is the parameter of the barrier design as well as its height. As the experience of barrier applications worldwide indicates there may be various barrier designs in accordance with the materials used and different dimensions.

The base of acoustic barrier design is made of a bearing frame and sound isolating part with additional sound absorption and protection layers. The effective barrier height H_e is determined in accordance with the calculation scheme presented in Fig. 4.

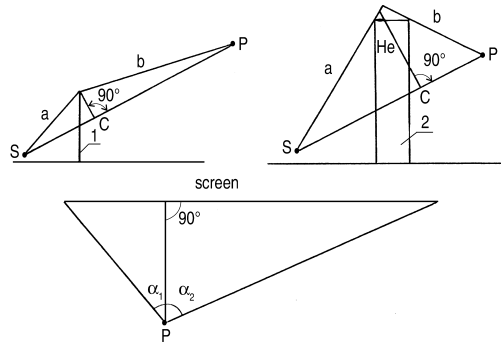


Fig. 4. Calculation schemes for determining the lowering of the noise level on the barrier: 1 – barrier, 2 – building, S – noise source, P – count point, H_e – effective height of the barrier

Calculation of simple barriers

In the final calculation, when we have the characteristics of the barrier, in order to evaluate the qualitative side of the screen we have to follow the theory of diffraction [6].

In order to obtain sound pressure at a certain point P in zone of the shadow, behind the barrier it is necessary to integrate energy, radiating by every single elementary volume of the wave front, acting as the qualitative new source point in the free space above the barrier.

Many authors [6, 7] proposed their own theories that analyze different conditions of the fall of the sound waves. Strong and accurate decisions are used only for very clean and simple conditions, which do not exist in the reality. Besides that simplicity is good for practical calculations and may be successfully applied in designing the barriers aimed for protection of noise.

The sound field in the point P, after having passed through the window makes itself the factor of diffraction (DF) on the field in the free space.

Here we are going to analyze semi-infinite thin screen with the point source. For the simplest case semi-infinite flat screen is installed between the points S and P with the values u_1

$$DF = \frac{-i}{2}(1+i) \left\{ \left[\frac{1}{2} - C(v_1) \right] + i \left[\frac{1}{2} - S(v_1) \right] \right\} \quad (1)$$

Lowering of noise by means of semi-infinite barrier is expressed in the following (2)

$$\Delta L_{1/2} = -10 \lg |DF|^2 = -10 \lg \frac{1}{2} \times \left\{ \left[\frac{1}{2} - C(v_1) \right]^2 + \left[\frac{1}{2} - S(v_1) \right]^2 \right\} \quad (2)$$

where the bracketed terms correspond to the square of the absolute value of the vector v_1 . The graph in Fig. 5 demonstrates the results of calculations by means of the equation (2). The area of negative and positive values corresponds to the position of the point P in the zone of the shade and out of the shade.

The equation (2) received from the theory of diffraction in optics has got a very simplified view and most clearly represents the physical essence of the phenomenon. It is unfortunate that a good approximation with optical diffraction does not ensure the same accuracy in the acoustics. In optics the length of the waves are very low, at the same time the distance from the source to the obstacle and further on to the observer is high enough. The conditions in acoustics are quite different that is why when designing acoustic structures and screens it is recommended to apply empirical data.

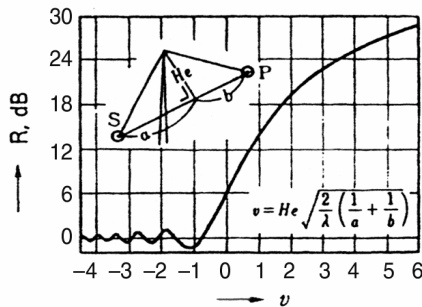


Fig. 5. The calculated lowering of sound of semi-infinite barriers following the theory of diffraction of Kirchhoff (for comparison with free space)

Analysis of theory and practical implementation

The efficiency of barriers for noise reduction depends on the characteristics of the sound isolation and sound absorption as well as on the above aforementioned characteristics. Based on the theory presented in [4, 5] it was determined that in the acoustic barriers after application of cone element it is possible to increase the isolation and sound absorption characteristics of the aforementioned used barriers. Special noise absorbers with cone element installed on the barriers (Fig. 6) not only absorb low frequency sound better, but also improve sound isolation.

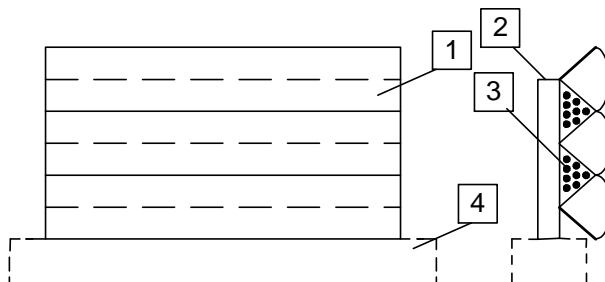


Fig. 6. The barrier model with the cone elements.

1. Plate, 2 Stand, 3 Sound absorption of cone element, 4. Foundation

Analysis of results allows to state that after using cone elements for the structures of acoustic barriers, the characteristics of sound absorption and isolation would increase, particularly under low frequencies (Fig. 6).

Sound reflected from the barrier actuates the vibrations of the barrier of the screen, which also radiates sound corresponding frequencies. So the vibrations induced by the barrier should be very low frequency or very high frequencies, namely in the range of not audible sound frequency.

The proposed acoustic barrier to be viewed as a equipment with specially designed sound absorbers, that not only absorb the reflected sound but also improves the characteristics of barrier sound isolation.

Conclusion

While studying low-frequency sounds, which are propagated from railway transport, it was established that audible low-frequency sound is accompanied by infrasound. It was determined that infrasound has negative impact on the individuals and fauna.

Study indicates that for application of acoustic barriers for noise reduction it is required to carry out theoretical and experimental assessment. For theoretical assessment it is required to possess characteristics of the intended noises to be reduced as well as to have the requirements for barriers to be applied together with geometric values.

The reported research work proposes application of classical *Fresnel-Kirchhoff approximate theory* in determining the efficiency of the chosen screens. In analyzing the acoustic characteristics of a barrier it is required to isolate and absorb the sound energy approaching the barriers. Acoustic characteristics depend on the materials and dimensions that have been selected for the screens.

While making use of the qualities of the materials for barriers and the shapes of the structures it has been determined that barrier sound isolation and absorption depends on the separate characteristics of acoustics of single elements used here, such as rigidity (in changing the shape of the element), porosity, etc. Performed analysis indicates that implementation of cone-type elements enables significant improvement of sound isolation characteristics of the barrier, in particular at low frequencies when the barrier weight is not increased. The paper proposes a new design of barriers employing conical elements. Their advantages were confirmed theoretically and partially implemented in practice.

References

- [1] **European Commission:** Progress report on Rail Baltica compiled by the European coordinator of the project. July 2007- July 2008. P.24.
- [2] **European Commission:** Feasibility study on Rail Baltica railways - Main conclusions and recommendations. January, 2007.
- [3] **European Commission:** Feasibility study on Rail Baltica railways - Annexes. January, 2007.
- [4] **Gužas D., Klimas R., Tričys V.** "Influence of Rigidity of Acoustic shield Walls on Sound Insulation"/ *Mechatronic Systems and Materials, MSM 2005, A Collection of Papers from the 1st International Conference: MSM 2005, Vilnius, Lithuania 20–23, October 2005–2006, Solid State Phenomena* Vol. 113, pp. 252–258, (2006).
- [5] **Gužas D., Klimas R.** "On the development and practical application of the theory of sound insulation of cylindrical shells"/ *Ultrasound* Nr. 1(58), (Technologija, Kaunas), pp. 50–54, (2006).
- [6] **Maekawa Z., Lord L.** „Environmental and architectural Acoustics” 2004, p. 377 Z. Maekawa et al.: „Some Problems on Noise Recuction by Barriers“ *Proc. Sympo. Noise Prevention* (Miskolc 1971). L. Wirt „The Control of Diffracted Sound by Means of Thnadners“ (Shaped Noise Barriers) *Acustica*: 42–2, pp. 73–88, (1979).
- [7] **Fujiwara K, et al.** „Noise Control by Barrier – Part 2: Noise Reduction by an Absorptive Barrier“ *Appl. Acoust.* 10 pp.167–179, (1977) T. Isei, T. F. W.Embleton & J. E. Piercy, „Noise reduction by barriers on finite impedance ground“ *J. Acoust. Soc. Am.* 67–1 46–58, (1980) Revised.