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IN-SITU SOUND REFLECTION DETERMINATION OF RUCONBAR NOISE BARRIERS ON A RAILWAY LINE

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Abstract

Noise pollution has a heightened sensitivity given recent developments at the EU level and the publication of updated noise guidelines by the World Health Organization. One of the main noise control methods is mitigation at the sources by building the noise barriers. Besides mechanical and durability properties, the acoustic performance indicators of the noise barrier are their most important properties. RUCONBAR is a highly absorptive environmentally friendly concrete noise barrier developed and patented at the Faculty of Civil Engineering University of Zagreb. Its absorbing layer is made of recycled waste tires and concrete. The use of RUCONBAR on railway track sections of the railway line M604 Oštarije-Knin-Split is the first time that noise barriers are applied on a section of the railway infrastructure in Croatia. This paper presents in situ measurements of the insertion loss and sound reflection of RUCONBAR barriers near Gospić train station. In situ values of sound reflection of the barrier under direct sound field conditions are measured according to the standard HRS CEN/TS 16272-5. The measurement is conducted by using an artificial sound source. For calculating sound reflection index, the impulse responses are acquired and analysed. Differences between obtained results of the sound reflection related to the direction of the measurement are finally discussed.

Keywords: noise pollution, railway, noise barrier device, sound reflection

1 Introduction

The migration of the population from rural to urban areas, the development of transport infrastructure, and the increase in the number of vehicles have a significant impact on increasing noise levels. To ensure the environmental sustainability of transport infrastructure, in June 2002 the EU adopted Directive 2002/49 / EC [1] on the assessment and management of noise, in particular in the areas adjacent to motorways and railways.

Measures to reduce noise and vibration from railway transport are classified into four basic groups: reduction of noise and vibration at source, reduction of noise and vibration propagation, protection against noise and vibration at the point of immission, and economic measures and regulations. The noise reduction effect of a railway noise barrier depends on its height and the relative distance between the source, the barrier, and receiver positions [2]. By analyzing the noise reduction barrier effect, it is necessary to consider the close relationship between acoustic performance and environmental factors, such as ground effect, atmospheric turbulence, air absorption, refraction by wind, and temperature gradient profiles [3,4]. The use of noise barriers is the most common and efficient way to reduce noise. Traffic noise barriers reduce noise at the point of immission in the amount of 5 to 15 dB, depending

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on their height, length, material, and the distance between the source and receiver [5]. The effect of reducing the noise level on the projected level is achieved immediately after installation. The dimension of the constructed noise barriers varies from 2-5m in height. Their lengths usually depend on the size of the area to be protected.

European standards for testing noise barriers that affect the propagation of airborne sound are divided into package related to road infrastructure and into package related to railway infrastructure. A package of standards for testing the properties of barriers on road infrastructure CEN / TC226 / WG6 was defined in 1989. A package of standards for railway infrastructure was developed by CEN / TC256 / SC1 / WG40 in 2008. Most of the standards for road infrastructure barriers are within the CPR package 305/2011 [6]. In the railway sector, noise barriers are considered outside the scope of CPR 305/2011, but must comply with the TSI (Technical Specifications for Interoperability). Standards for noise barrier testing are classified into three groups: standards related to the acoustic characteristics of barriers; standards related to mechanical and safety; and standards that define their lifespan and sustainability [7].

There are generally two types of acoustic barriers: reflective and absorbing. The main difference between these two types of barriers is that the reflective ones reflect sound waves without reducing their intensity, while the absorbing ones “receive and trap” part of the sound energy and reflect the sound wave of reduced intensity. Absorbing barriers are usually made opaque, while reflective barriers can be made of opaque but also transparent materials. According to research [8], the use of absorbing barriers is more common. Reflective barriers can be problematic for buildings on the opposite side of the transportation infrastructure. Namely, if there is another road near the mitigated sound source from which the building is protected, there is a chance to increase the noise caused by traffic on that unprotected road. By setting up a reflective barrier, reverberant sound field conditions are created in which the sound is reflected and there is an increase in sound waves that reaches the objects on the opposite side of the nearby road. For the needs of building noise barriers, there are panels on the market today made of different materials, and the most commonly used are: concrete, wood, aluminum, and transparent materials. The absorption layer of concrete barriers is usually made with the addition of wood fibers (wood-concrete barriers) or expanded clay granules. By applying these materials, we act contrary to sustainable development. Directive 2008/57 / EC defined the basic requirements in terms of environmental impact: the impact of the railway system on the environment must be assessed at the design stage. Railways must meet all noise emission requirements prescribed by existing regulations [9].

RUCONBAR (Rubberized Concrete Noise BARriers) is an innovative solution developed as part of scientific research at the Faculty of Civil Engineering [10-13].

Regarding the acoustic characteristics in the development of RUCONBAR so far, laboratory tests for sound absorption, research was conducted on laboratory and real samples of 10.0 m^2 in the reverberation chamber in accordance with HRN EN ISO 354: 2004 and HRN EN 1793-1: 1999. Based on the obtained results, the RUCONBAR barrier is classified in class A3 of sound absorption based on a single value of sound absorption DLα = 8.7 dB [14]. In addition to extremely good and competitive sound absorption properties, the RUCONBAR barrier has improved and other significant properties such as frost and thaw resistance and fire resistance. RUCONBAR was later also tested according to railway standard HRN EN 16272-3-1:2013 and obtained value of the sound absorption is DLα = 8 dB [15].

The first application of RUCONBAR innovative barriers for noise protection was In 2014. On the section of the state road, near the island of Krk. The application of the product was also realized by noise protection from the railways on the railway line M604 Oštarije-Knin-Split.

This paper presents the in-situ measurements of the sound reflection of the RUCONBAR barrier for noise protection installed on railway infrastructure.

Conducting the measurements of the sound reflection on the RUCONBAR noise protection walls installed on the Oštarije-Knin-Split railway section provides:

- additional optimization of the RUCONBAR noise barrier system
- the possibility of participating in an increasing number of tenders for the installation of noise protection systems on railway infrastructure in the Republic of Croatia and other EU members
- a competitive advantage with products without confirmation of properties carried out according to the subject standards.

2 In-situ determination of the RUCONBAR sound reflection

To upgrade the data on the acoustic properties of the RUCONBAR noise barrier, in-situ measurement of the sound reflection is performed. In this way, the product competitiveness in the market increases and indicates the potential optimization of product properties. The method of calculating sound reflection of noise barriers applied on railway infrastructure is defined in the standard HRN EN ISO 1762-5 [16].

2.1 Measuring procedure

The RUCONBAR sound reflection is measured in the vertical and horizontal directions. It is calculated by averaging the values of all measurement steps performed according to the standard in the given angle changes of the emitting sound wave. The measurement is conducted for 9 position angles at which the speaker and microphone are placed (50 °, 60 °, 70 °, 80 °, 90 ° - referential, 100 °, 110 °, 120 °, 130 °).

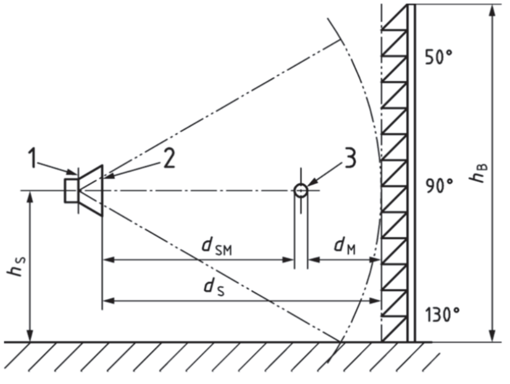

Figure 1 Sound reflection index measurements (1-rotation axe;2-loudspeeker;3-microphone

The value of h_s is the reference height, while h_b is the height of the noise barrier. The d_m symbol indicates the horizontal distance from the microphone to the reference circuit ($d_m = 0.25$ m). The distance d_{sm} is the horizontal distance from the front of the amplifier to the reference circuit and is equal to $d_{sm} = 2.25$ m. The measurement of the sound reflection index in this standard conducts in that the source emits a sound wave propagating towards the tested barrier. Also, the measurement of the sound wave emitted from the same source is conducted in the free-field sound conditions (sound source pointed toward area with no obstacles). The wave passes the microphone and bounces off the tested barrier. The microphone is placed between the sound source and the tested barrier. It receives direct sound pressure waves (direct sound wave propagating from the source to the barrier, and direct sound wave bouncing against the tested barrier). The data on the power spectrum of the direct sound wave emitted in free-field and data of the reflected wave are the basis for calculating the sound reflection index.

$$RI_j = \frac{1}{n_j} \sum_{k=1}^{n_j} \frac{\int_{\Delta f_j} \left| F\left[t \cdot h_{rk}(t) \cdot w_r(t) \right] \right|^2 df}{\int_{\Delta f_j} \left| F\left[t \cdot h_i(t) \cdot w_i(t) \right] \right|^2 df} \tag{1}$$

Calculation of the values of the sound reflection RI_j in third frequency bands from 100 Hz - 5000 Hz depends on the component of the impulse response of the free- field sound wave (h_i); and on the component of the impulse response of the reflection wave (h_{rk}).
The individual value of the sound reflection (reflection) index is determined according to the normalized noise spectrum on the railway defined in [17]. It depends on the index of sound reflection measured in front of the acoustic element (RIi) and on the relative A-rated sound pressure level (dB) of the normalized spectrum for rail traffic noise (Li).

$$DL_{RI} = -10 \cdot lg \left[\frac{\sum_{i=m}^{18} RI_i \cdot 10^{0,1L_i}}{\sum_{i=m}^{18} 10^{0,1L_i}} \right] \tag{2}$$

2.2 Shortcomings of the method

For the application of the method, the measurement setup demands high precision. Many locations cannot be well analyzed because of the terrain characteristics. Even little movement of the measuring setup can result in high uncertainty in obtained results. The noise barrier acoustic layer has its geometry, and it is important to conduct the measurement on just that part of the barrier. It is very challenging to aim the sound wave from the sound source (loudspeaker) on a 1.5-meter distance barrier when the slope of the terrain is high. The recommendation of the standard is to complete the test within 20 minutes, and this is almost impossible in inaccessible terrain with a microphone and speaker at high altitude.
Also, the condition of the standard method [16] regarded on the inclusive third frequency bands results in omitting some bands because of the geometry of the noise barriers applied on Croatian railway infrastructure. Namely, barrier heights rarely exceed 3 m, the analysis cannot cover the low-frequency spectrum (lower than 315 Hz).
Due to various angles of measurement of the sound reflection, and reflection of sound from the ground resulting in the creation of unwanted noise, it is necessary to omit certain records of low-frequency sound measured for certain angles.

3 Location of the measurement

Determination of the RUCONBAR sound reflection index calculates according to the method defined in the standard [16]. The measuring point of the sound reflection index MPrefl is on the track stationing km 116+739 (10 m southern from the end of the southern noise barrier made near Gospić station), in front of the wall for protection against noise, Figure 2. The source of the sound (loudspeaker) is 1.5 m away from the axis of the wall. The height of the loudspeaker placed at the measuring point MPrefl is half the height of the barrier (1.5 m). The microphone is placed at 0.25 m from the barrier. The positions of the microphone and loudspeaker move following the standard requirements according to which the reflection of sound is determined.

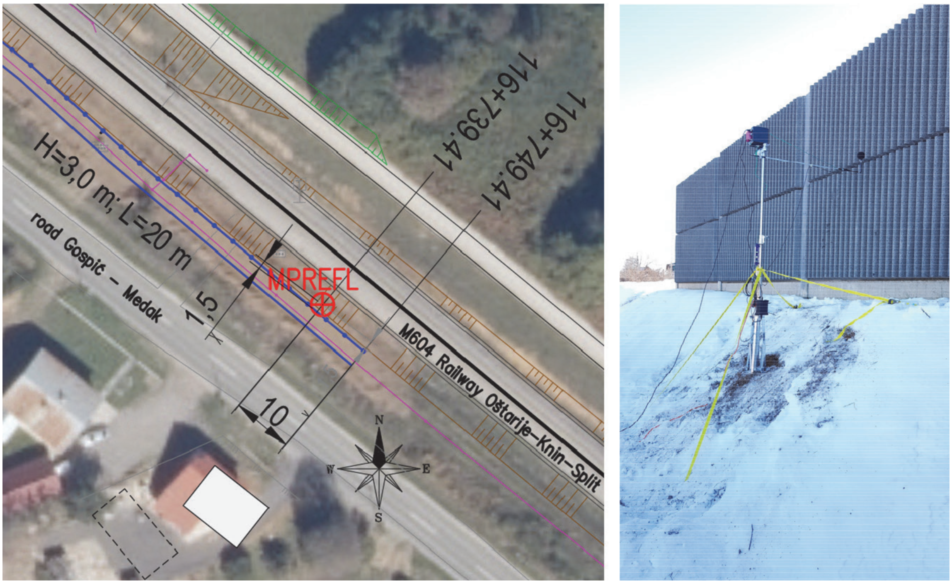

Figure 2 Sound reflection measuring position

4 Analysis of the results

This chapter presents the results obtained according to the standard for testing the value of the sound reflection index [16] and a single value that defines the reflection of the tested barrier [17]. The processing of the results of the sound reflection of the barrier is carried out for the frequency range for which reliable results can be obtained, defined by the standard [16]. For barriers of 3 m height, the recommended lower limit frequency is 300 Hz. For certain angles at which the test is performed, the standard prescribes which frequency bands can be taken into analysis. Given the height of the barrier (3 m) and the limitations given by the standard, the effective frequency range covered by this test is from 315-5000 Hz.

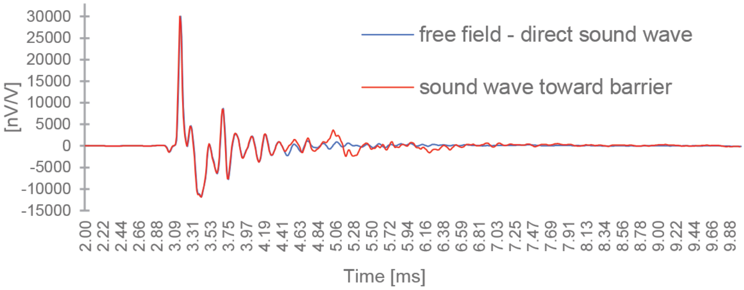

Figure 3 Difference between free-field sound wave and sound wave emitted toward the barrier

The sound reflection index is calculated from the ratio of energetic quantities extracted from impulse responses taken using the same loudspeaker-microphone assembly within a short-time period. Measurement is conducted using single-driver active speaker in accordance with standard [16], class 1 microphone (Brüel&Kjael 2270), and a professional soundcard. The emitted sound signal was generated in sample rate of 96 kHz. Signal time synchronization and averaging of 16 emitting sound signals for every measurement angle were performed in ARTA software.

The electro-acoustic source receives an input electrical signal which is deterministic and exactly repeatable. The input signal has to be set in order to avoid any nonlinearity of the loudspeaker. The S/N ratio is improved by repeating the same test signal and synchronously averaging the microphone response. In standard [16] is recommended to use an MLS signal as test signal. Alternatively, a different test signal allowed according to the standard, and used in this work is sine sweep test signal.

Measurements of impulse responses via the Dirac function are conducted in (a) free-field environment where the speaker is facing towards open space with no obstacles) and (b) non-free-field environment where the speaker is facing the observed noise reducing barrier at a certain angle (Figure 1). Such two impulse responses are synchronized in time domain.

Figure 4 shows the sound wave in the free-field condition and the sound wave emitted towards the barrier at an angle of 90º (non-free-field condition) where the difference in signal can be observed 1.5 ms after 1st peak in the signal which corresponds to occurrence of a wave reflected from noise reducing barrier. The next step of the analysis is subtraction of the free-field (direct) signal from the non-free-field signal to isolate the reflected component.

Furthermore, it is necessary to eliminate other influences (sound diffraction, delayed reflections) with the help of the defined Adrienne temporal window with total duration of 9.4 ms. The Adrienne temporal window was created for the free-field (direct) and reflective part of the processed signal, Figure 4. According to the recorded temperature data and the air humidity during the measurement, following the expression $\tau = 2d_m / c$, the delay of the reflective part of 1.5 ms was calculated.

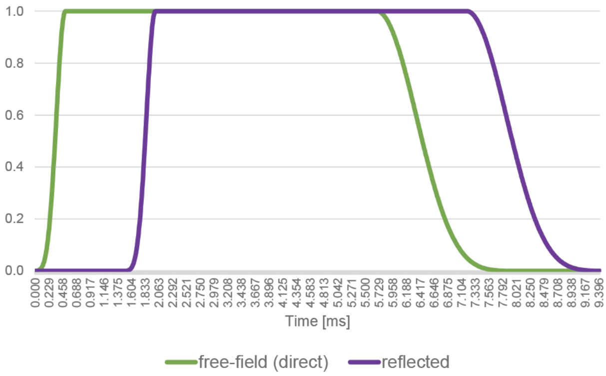

Figure 4 ADRIENN window for free-field (direct) and reflected sound wave

4.1 Results of the RUCONBAR sound reflection measurement

Depending on the depth of the absorbing layer, there are flat and non-flat noise-reducing devices [16]. RUCONBAR barrier at the described location is considered a non-flat barrier with an absorbing layer formed as a repeatable undulating surface with a wave amplitude of 9 cm and wavelength of 12 cm, as shown in Figure 5.

The test is performed according to the scheme (Figure 1) in the range from 50° to 130°. The sound reflection coefficient RIj results for individual third frequency bands are obtained according to equation 1. The calculation was conducted separately depending on the direction of the test (vertically along with the barrier height – along undulation ridge - RI_j V; and horizontally, along the barrier width – perpendicular to undulations - RI_j H), illustrated in Figure 6.

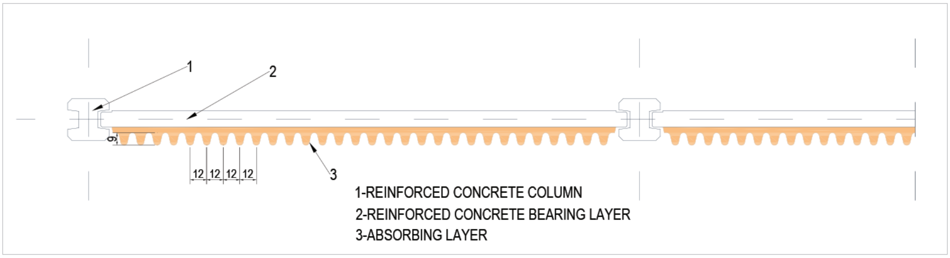

Figure 5 Top view of the RUCONBAR noise barrier

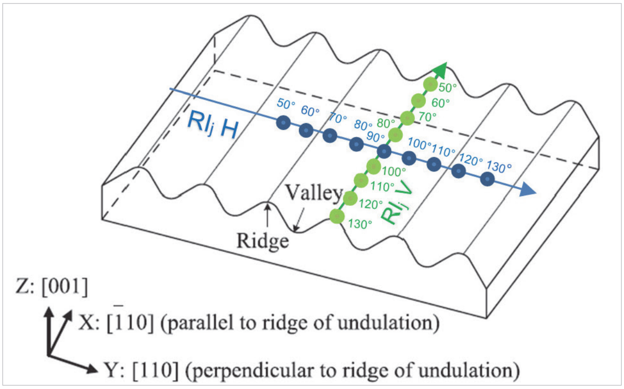

Figure 6 Schematic structure of the undulant substrate [18]

The average values of the sound reflection coefficient RIj for both directions in all frequency bands are shown in Figure 7. The single numbered value of the sound reflection index is calculated following HRN EN 16272-3-2 [17]. According to equation 2 it is 5 dB in the vertical direction and 7 dB in the horizontal direction.

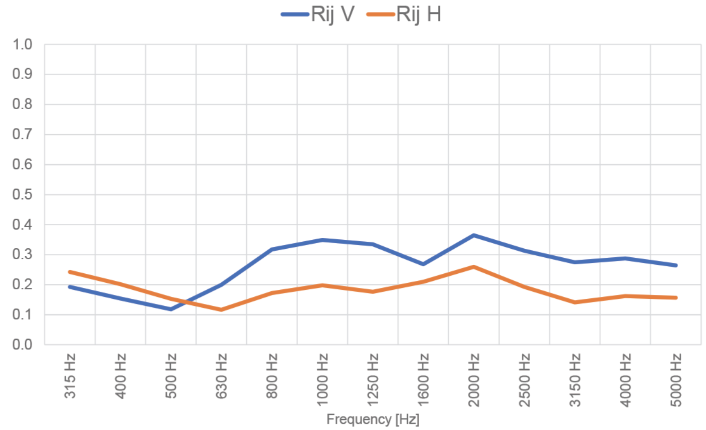

Figure 7 Coefficient of sound reflection in the vertical and horizontal directions

4.2 Optimizing RUCONBAR according to obtained sound reflection values

Based on the analysis of sound reflection results, it is possible to compare the reflection coefficients obtained by in-situ testing and the sound absorption coefficients (1-αs) obtained by laboratory testing [15] because the reflection values and absorptions are inversely proportional, Figure 8.

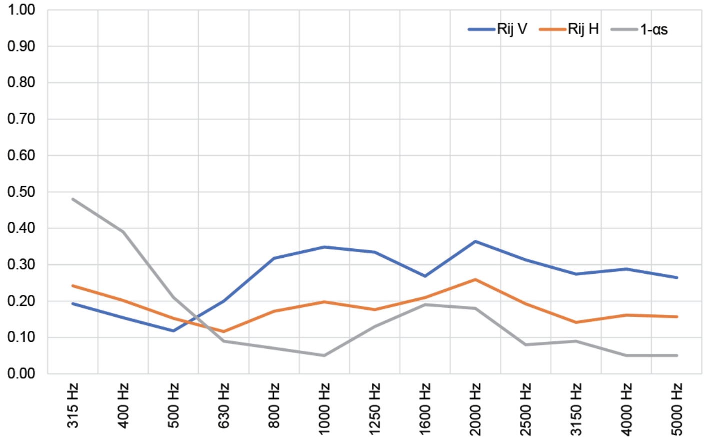

Figure 8 Comparison of the sound reflection index in the horizontal and vertical directions and the absorption index obtained by laboratory testing

By comparing laboratory and in-situ tests of sound absorption/reflection coefficients, on a very large number of tested samples (284 tested barriers) within the Sopranoise project [19], an approximate ratio of a uniform absorption value was obtained, and it is equal to $DL_{RI} \approx 2/3\ DL\alpha$.

In the case of the RUCONBAR barrier test, this approximate ratio is also satisfied, considering that a single-numbered value of the sound reflection in the vertical direction equals $DL_{RI},_{V} = 5\ dB \approx 2/3\ DL\alpha = 8\ dB$.

Comparing the obtained values of the single-numbered sound reflection indices (DL_{RI}) in the horizontal and vertical directions, a significant difference in the reflection at a greater deviation from the direction perpendicular to the barrier (90°) is visible. The direction of the test perpendicular to the undulation ridge gives higher DL_{RI} values if individual values are calculated for each of the tested angles. Figure 9 shows that the minimum value of the sound reflection index at angles 90° - 130° in the vertical measurement direction, indicates the reflection of sound from the ground. A significantly higher one-dimensional sound reflection index was obtained in the horizontal direction, which indicates a higher property of sound absorption in the plane perpendicular to the direction of extension of the undulation ridge in the absorbing layer.

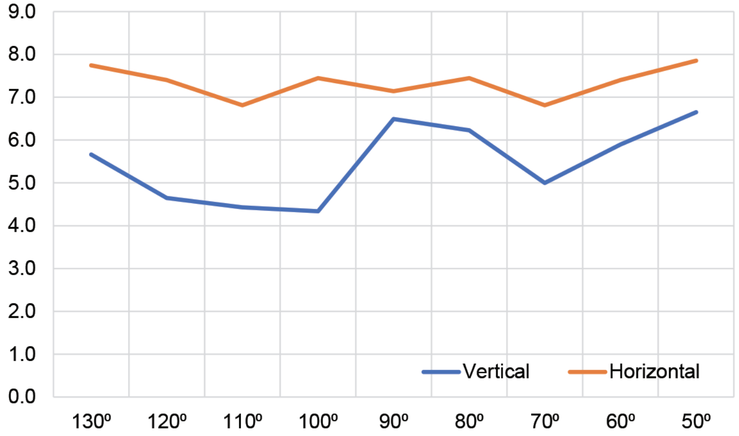

Figure 9 Graphical representation of single-numbered values of the sound reflection index for individual angles measured parallel to the undulation ridge (Vertical) and perpendicular to the undulation ridge (Horizontal)

5 Conclusion

Significant investments in railway infrastructure in the future in the Republic of Croatia are the motivation for the implementation of project activities aimed at optimizing RUCONBAR barriers for use on railways. The main objectives should be proving their effectiveness and better positioning in a very competitive market of noise barriers. Proven in-situ acoustic product performance is an increasingly common requirement. The installation of RUCONBAR barriers near Gospić on the railway section of the M604 Oštarije-Knin-Split line provided the testing of the in-situ acoustic performance of this type of concrete barriers for noise protection.

Based on the conducted sound reflection tests, it is possible to check the in-situ performance of the RUCONBAR noise barrier, complementary to the laboratory test of sound absorption, but in realistic conditions of the installed barrier. The results of single-numbered sound reflection values and reflection at different frequency bands show high agreement with the results of laboratory tests.

The analysis of the results indicates significantly higher sound absorption properties measured in the direction perpendicular to the undulating ridge (horizontally) than measured parallel to the barrier undulation ridge (vertically). This result can imply that positioning of undulation direction parallel to horizontal plane could result in significant increase in sound attenuation. Such experiments are to be conducted on new test samples produced by Beton Lučko in next steps of product optimization.

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