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Acoustic Performance of Concrete with Rubber and Vermiculite for Highway Barriers

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The inadequate disposal of waste tires has caused environmental and public health problems. One of the direct harmful effects is the noise due to traffic. Waste rubber has been used in concrete to improve its acoustic performance and energy absorption. Studies carried out by the U. S. Federal Highway Administration show that barriers, regardless the material used, do not block completely but can reduce the volume of traffic noise by half. This study proposes concrete mixes containing waste tires and vermiculite to verify their acoustic properties for road barriers. The experiments include concrete with waste tires and vermiculite to replace the sand mass from 10% to 40%. An improvement in the acoustic properties was observed, reducing the total sound intensity level of the concrete acoustic barrier to 20 dB and 29 dB, for the frequencies of 500 Hz and 1000 Hz, respectively.

Keywords: *Concrete barrier, rubber waste, vermiculite, acoustic performance.*

1. Introduction

High levels of noise pollution cause damage to physical and mental health, with motor vehicles on tires being the main sources of noise in urban and road environments. The production and import of new tires, as well as the disposal of waste tires, lead to serious environmental and public health problems.

To properly allocate rubber residues, they have been used in cement composites to improve some of their properties in the hardened state. The installation of acoustic barriers is an option to minimize the high levels of noise, and, in this context, this research evaluates the incorporation of rubber and vermiculite residues in concrete regarding the acoustic properties as a noise attenuation coefficient.

A dosage study was carried out to determine the reference mix of cementitious composites, containing only natural aggregates. Subsequently, the different concrete compositions were defined with the addition of rubber and vermiculite residues to replace the mass of natural sand at the levels of 10%, 20%, 30% and 40%.

These concretes were subjected to tests to determine the sound transmission loss, and the road traffic noise was calculated by the empirical model of the FHWA[1].

2. Literature Review

One of the direct harmful effects of transport on the environment is noise due to traffic. The noise level varies continuously in time and space, the noise intensity and frequency spectrum vary for each mode of transport, and the noise level reaching an observer depends on its distance from the source and the ambient noise[2-5].

In Brazil, the maximum noise level allowed for passenger and mixed-use vehicles is 80 dB[6]. Other specifications refer to the maximum permissible noise levels in the internal environments of a building[7] and depending on the types of inhabited areas and the period[8].

To mitigate noise from road traffic, natural or artificial screens are used in the right-of-way or outside it. Acoustic barriers are classified as reflective, absorbent or highly absorbent, depending on the characteristics of the place and the material of its structure, natural or artificial, and more than one process can be combined[9]. A wide variety of materials can be used to manufacture artificial sound barriers, such as: conventional concrete, porous concrete, acrylic, wood, block masonry, metallic material[10-12].

In addition to the barrier material, the surface treatment texture depends on several factors, including aesthetic requirements, executive techniques, maintenance and the type of barrier material. Noise barriers can be constructed with earth, concrete, masonry, wood, metal and other materials. To effectively reduce sound transmission through the barrier, the material chosen must be rigid and sufficiently dense (at least 20 kg/m^2). In general, it is desirable to locate a noise barrier at approximately four times its height from residential areas. Although acoustic barriers do not eliminate all traffic noise, they substantially reduce it and improve the quality of life for people living near busy highways[1].

Barriers can reduce the volume of traffic noise by half, do not completely block all traffic noise, can be effective regardless of the material used, must be tall and long, without openings, are more effective within about 60 meters of a roadway, they must be visually appealing; should preserve aesthetic values and scenic views and not noticeably increase noise levels on the opposite side of the road[13].

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Concrete is one of the most durable materials currently used in many road products, including acoustic barriers, which can be cast-in-place or prefabricated. Concrete is tough and able to withstand harsh temperatures, intense sunlight, moisture, ice and salt. It is a versatile material capable of being shaped, molded, and textured to take on a variety of appearances, from weathered wooden planks to rock and stone blocks. Its mass, even with a thickness of only 12 mm, satisfies any sound transmission class requirement. The versatility of concrete also extends to the shape and size in which the panels can be produced. Cast-in-place concrete barriers have been commonly used in bridges and retaining walls due to their design flexibility, high structural strength, and resistance to vehicle impact damage[13].

The sizes of precast barriers are normally confined, in one direction, to approximately 4.5 meters, due to transportation limitations, with no limit on length other than size and weight for handling. Minimum thickness is normally about 10.0 cm, plus an additional 2.5 cm to allow for reinforcement and any texturing surface. To verify the quality of the barrier, it is important to select samples that are a true representation of the finished product or materials used in the noise barrier design[13].

The reduction of sound pressure in barriers made of precast concrete panels is greater than in barriers made of concrete blocks and vegetation[11].

Concrete is an acoustic insulator due to its mass and physical characteristics. However, the traditional materials that constitute it can be replaced by light and porous materials such as vermiculite, rubber and expanded clay, to make it a sound-absorbing material[14].

CONAMA[15] considers that improperly disposed tires and provides for the prevention of environmental degradation caused by waste tires and their environmentally appropriate disposal. Rubber from scrap tires, when incorporated into concrete, in the form of fine or coarse recycled aggregate, reduces its compressive strength, tensile strength and modulus of elasticity, compared to conventional concrete[16,17]. On the other hand, concrete with rubber has a positive effect on other properties, such as: ductility, energy absorption capacity, fracture energy, damping, impact resistance and acoustic properties[18-23].

Expanded vermiculite is a lightweight aggregate that, when used in cement composites, reduces sound wave velocity and thermal conductivity, providing better thermoacoustic properties[24]. The use of waste tires associated with vermiculite in concrete is a way to provide better acoustic properties to concrete and comply with CONAMA[6,15,].

This research deals with the sound transmission loss of concrete compositions containing rubber and vermiculite together for the construction of acoustic barriers.

3. Methodology

3.1. Experimental

Five concrete mixtures were developed, which were subjected to tests to determine the sound transmission loss.

The fine aggregate was replaced by rubber and vermiculite in the following composition: 10% rubber and 40% vermiculite (B1-V4), 20% rubber and 30% vermiculite (B2-V3), 30% rubber and 20% vermiculite (B3-V2), 40% rubber and 10% vermiculite (B4-V1). The mass ratio of the concrete used corresponds to 1: 2.50: 2.50: 0.44: 0.043: 0.10: 0.005: 0.60 (cement: sand: gravel: rubber: vermiculite: silica: additive: w/c factor).

The materials used in the production of concrete were Portland cement CPV-ARI, expanded vermiculite, quartz sand, rubber from the tire retreading process, basaltic gravel, drinking water and a superplasticizer based on polycarboxylate ether. The rubber particles were sieved, and the material used was the passing through the 1.18 mm sieve. Vermiculite is a mineral composed of hydrated silicates of aluminum, iron and magnesium. vermiculite particles have a maximum size of 4.8 mm. The specific masses of the materials were 3.07 g/cm^3 for cement; 2.65 g/cm^3 for sand; 1.16 g/cm^3 for rubber; 0.45 g/cm^3 for vermiculite; 3.00 g/cm^3 for crushed stone; 2.21 g/cm^3 for silica fume.

The concretes were produced in an inclined shaft mixer with a capacity of 120 liters, tested at 28 days of age[25].

3.2. Calculation procedures

The test to determine the sound transmission loss (Transmission Loss TL) was carried out through the impedance tube, according to *ASTM E2611-09*[26]. This test was performed using cylindrical concrete specimens, 59 mm in diameter and 50 mm in height, as shown in Figure 1.

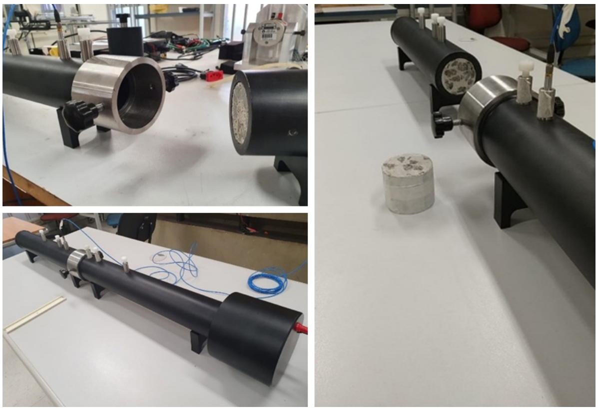

Figure 1. Test to determine sound transmission loss.

Chart 1 shows the experimental setup for the test conducted in the impedance tube (Model SWA SW 433). The practical test followed the Transfer Matrix One-load method of ASTM Norm E2611-09[26] by configuring the 02 channel, 01 source signal as a reference transfer function, and 01 microphone (PCB 378A14) response. The responses are measured in 04 locations to obtain 04 transfer functions (H_{1s}, H_{2s}, H_{3s}, H_{4s}) used to obtain the experimental STL curves. Chart 1 shows the specifications for all measurement instruments used in the experimental test.

Imprecision in this test method arises from sources other than the measurement procedure. Some materials are not uniform, so specimens cut from the same sample differ in their properties. There is uncertainty in deciding the location of the face of a very porous specimen. The most significant causes of imprecision are related to the preparation and installation of the test specimen. The specimen must be precisely cut, and the mounting condition must be reproduced as closely as possible between tests[26].

After carrying out the acoustic tests, the road traffic noise was calculated by the empirical model[1]. For the calculation, two scenarios were adopted, and the attenuation of the barrier ($A_{barrier}$) was determined[27], as in Equations 1, 2 and 3. The equivalent level of sound pressure was also determined, Equation 4, and the total sound intensity level, according to Equation 5, without and with the existence of the concrete barrier. The distances are schematized in Figure 2.

$$Abarrier = 10\,log\left(20\ .N\right) \tag{1}$$

$$N = \frac{2x\delta}{\lambda} \tag{2}$$

$$\delta = A + B - C \tag{3}$$

Where:
$A_{barrier}$ = attenuation by loss of barrier insertion.
N = Fresnel number.
λ = wavelength.

$$Leq\left(h\right)i = \left(Lo\right)_i + 10.log\left(\frac{N_i}{V_i.T}\right) + 10.log\left(\frac{15}{d}\right)^{1+\alpha} + \text{ Acombined} - 13 \tag{4}$$

Where:
Leq(h)i = equivalent sound pressure level of class i vehicles.
$(Lo)_i$ = sound level emitted by a certain type of vehicle (Figure 3).
V_i = average speed, in km/h.
N_i = number of vehicles that travel within one hour.
T = duration time for which *Leq* is desired, corresponding to Ni (one hour).
d = distance perpendicular to the traffic lane to the receiver, that is, the point where the equivalent level is to be estimated, in m.
α = sound absorption factor.

$$NI_{TOTAL} = 10.log\left(10^{\frac{Leq(h)_A}{10}} + 10^{\frac{Leq(h)_{CM}}{10}} + 10^{\frac{Leq(h)_{CP}}{10}}\right) \tag{5}$$

Where:
NI_{Total} = total sound intensity level.
Leq(h)i = equivalent sound pressure level - noise sources from vehicles (cars (A), light or medium trucks (CM) and heavy trucks (CP)).

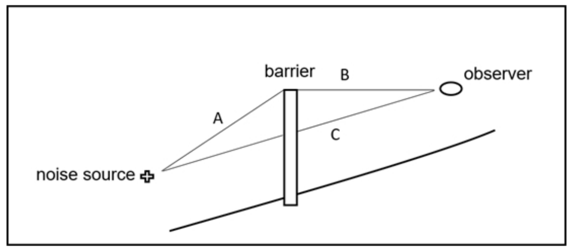

Figure 2. Distances from the acoustic barrier.
Source: Author

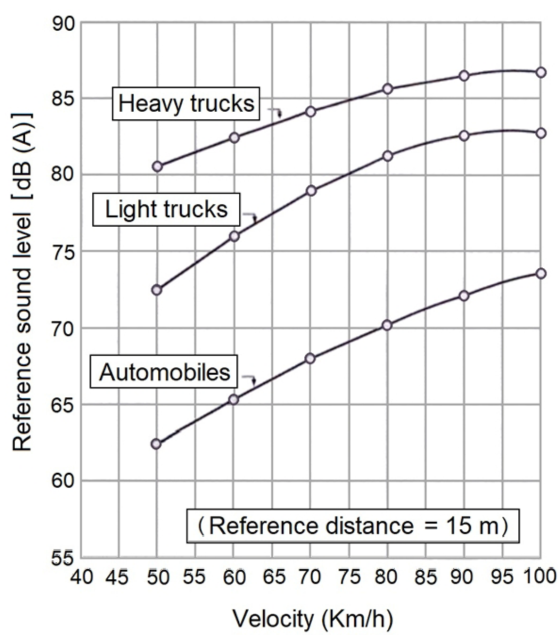

Figure 3. Reference sound level for vehicle classes as a function of V_i.
Source: FHWA[1]

Chart 1. Technical specification of the used measurement instruments.

Instrument	Manufacturer and model	Sensitivity	Measurement range
Impedance tube	SWA SW 433	-	10- 3.5e3 Hz
Microphone	PCB Piezotronics - 378A14	0.74 mV/Pa	4- 70e3 Hz
Data acquisition system	LDS Dactron - Photon II	-	Up to 84.2 kHz

4. Results and Discussion

The results of the tests referring to the sound transmission loss (TL) are shown in Figures 4, 5, 6, 7 and 8. The values of the average sound transmission loss, for the frequencies of 500 and 1000 Hz are shown in Table 1.

To verify the total sound intensity level from road traffic, two scenarios were adopted, considering in each of them the absence and insertion of a concrete acoustic barrier of traces: REF, B1-V4, B2-V3, B3-V2 and B4-V1.

In both scenarios, the following situation is assumed: circulation of 1750 cars, 550 medium trucks and 200 heavy trucks, at an average speed of 80 km/h, for the equivalent sound level in a period of one hour. For comparative purposes, noise levels were calculated as a function of the distance from the central axis of the highway for the hypothesis of installing a barrier at 15 m from the axis, with a height of 4.0 m, compared with the noise propagation condition without barrier.

For Scenario 1, a single-lane highway with a concrete barrier is considered 177 m from the receiver. In this scenario, as shown in Figure 9, the sound source is 23 m from the barrier and 200 m from the receiver, for frequencies of 500 and 1000 Hz, which are shown in Table 1. Tables 2 and 3 show the attenuation due to loss of barrier insertion, the total sound intensity level, on a highway without and with a barrier, for the frequencies of 500 and 1000 Hz, respectively. Consider $\lambda = 0.68$ m for the frequency of 500 Hz, and $\lambda = 0.34$ m for the frequency of 1000 Hz.

In Scenario 2, a single-lane highway with a concrete barrier is considered 50 m from the receiver. In this scenario, as shown in Figure 10, the sound source is 15 m from the barrier and 65 m from the receiver, for frequencies of 500 and 1000 Hz. Tables 4 and 5 show the attenuation due to loss of insertion of the barrier, the level of total sound intensity, on highways without and with barriers, for frequencies of 500 and 1000 Hz, respectively.

Figures 9 and 10 illustrate the values of sound levels calculated in the three scenarios, for varying distances from the roadside (15 m from the central axis) to 200 m, for 500 and 1000 Hz, respectively.

From 250 m, the natural reduction of sound propagation guarantees the maintenance of the legal limit of 60 dB, even without acoustic barriers. There are clearly the two important effects, the natural sound reduction with the distance and the reduction of the noise level with the installation of barriers. Even if, for legal reasons, the acoustic barrier is not necessary, its effect remains clear, as with the barrier the sound level reduces between 20 and 29 dB compared to the condition without a barrier, reaching a sound level near 50 dB, being confused with background noise in urban areas[9].

The results shown in Figures 11 and 12 show that the insertion of the barrier reduced the total sound intensity level from 20 to 24 dB for the 500 Hz frequency, and from 24 to 29 dB for the 1000 Hz frequency, for the proposed scenarios.

In the study by Batista et al.[28] it was found that with the increase in rubber content there was a decrease in the speed of sound propagation and an increase in the acoustic attenuation coefficient when non-destructive testing was carried out using ultrasonic waves.

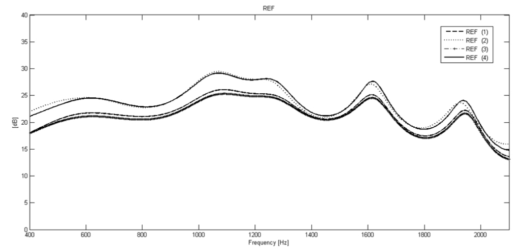

Figure 4. Sound Transmission Loss for the concrete mix REF.

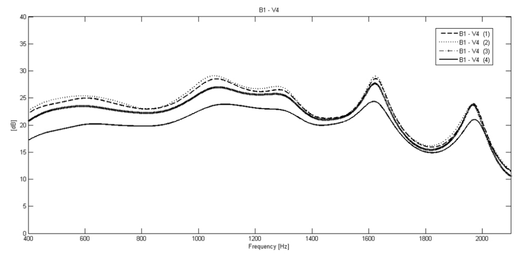

Figure 5. Sound Transmission Loss for the concrete mix B1-V4.

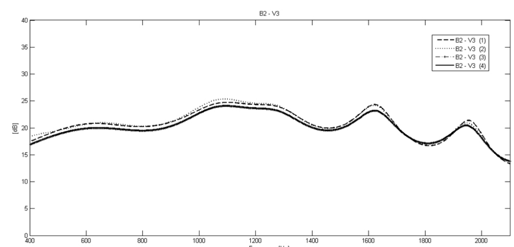

Figure 6. Sound Transmission Loss for the concrete mix B2-V3.

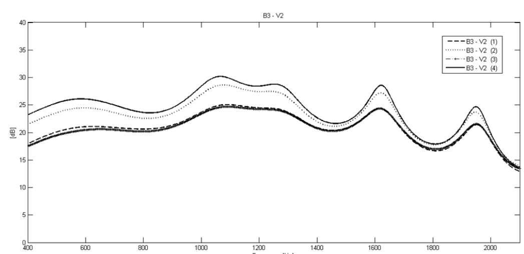

Figure 7. Sound Transmission Loss for the B3-V2 concrete mix.

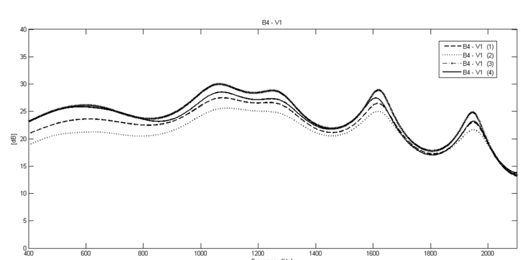

Figure 8. Sound Transmission Loss for the concrete mix B4-V1.

Table 1. Average sound transmission loss for frequencies 500 and 1000 Hz.

Materials	**Sound Transmission Loss** (dB)	
	500 Hz	**1000 Hz**
REF	23.03	28.53
B1-V4	23.65	28.15
B2-V3	20.07	24.28
B3-V2	23.30	28.39
B4-V1	23.29	27.68

Table 2. Sound attenuation by insertion of barrier at frequency 500 Hz for Scenario 1.

Traces	**Barrier-free total sound intensity level** (dB)	$A_{barrier}$ (dB)	**Sound Transmission Loss** (dB)	$A_{combined}$ (dB)	**Full sound intensity level with barrier** (dB)	**Reduction of total sound intensity level due to barrier** (dB)
Reference	68.92	9.54	23.03	23.22	45.70	23.22
B1-V4	68.92	9.54	23.65	23.82	45.11	23.81
B2-V3	68.92	9.54	20.07	20.44	48.48	20.44
B3-V2	68.92	9.54	23.30	23.48	45.44	23.48
B4-V1	68.92	9.54	23.29	23.47	45.45	23.47

Table 3. Sound attenuation by insertion of barrier at frequency 1000 Hz for Scenario 1.

Traces	**Barrier-free full sound intensity level** (dB)	$A_{barrier}$ (dB)	**Sound Transmission Loss** (dB)	$A_{combined}$ (dB)	**Full sound intensity level with barrier** (dB)	**Reduction of total sound intensity level due to barrier** (dB)
Reference	68.92	12.55	28.53	28.64	40.28	28.64
B1-V4	68.92	12.55	28.15	28.27	40.65	28.27
B2-V3	68.92	12.55	24.28	24.56	44.36	24.56
B3-V2	68.92	12.55	28.39	28.50	40.42	28.50
B4-V1	68.92	12.55	27.68	27.81	41.11	27.81

Table 4. Sound attenuation by insertion of a barrier at the frequency 500 Hz for Scenario 2.

Traces	**Barrier-free full sound intensity level** (dB)	$A_{barrier}$ (dB)	**Sound Transmission Loss** (dB)	$A_{combined}$ (dB)	**Full sound intensity level with barrier** (dB)	**Reduction of total sound intensity level due to barrier** (dB)
Reference	73.80	11.99	23.03	23.36	50.44	23.36
B1-V4	73.80	11.99	23.65	23.94	49.87	23.94
B2-V3	73.80	11.99	20.07	20.70	53.10	20.70
B3-V2	73.80	11.99	23.30	23.61	50.19	23.61
B4-V1	73.80	11.99	23.29	23.60	50.20	23.60

Table 5. Sound attenuation by insertion of a barrier at the frequency 1000 Hz for scenario 2.

Traces	**Barrier-free full sound intensity level** (dB)	$A_{barrier}$ (dB)	**Sound Transmission Loss** (dB)	$A_{combined}$ (dB)	**Full sound intensity level with barrier** (dB)	**Reduction of total sound intensity level due to barrier** (dB)
Reference	73.80	15.00	28.53	28.72	45.08	28.72
B1-V4	73.80	15.00	28.15	28.36	45.45	28.36
B2-V3	73.80	15.00	24.28	24.77	49.04	24.77
B3-V2	73.80	15.00	28.39	28.59	45.22	28.59
B4-V1	73.80	15.00	27.68	27.91	45.89	27.91

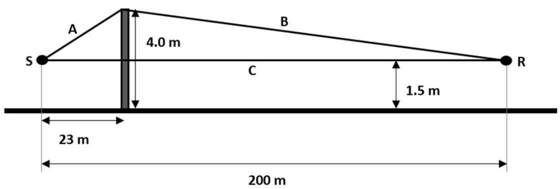

Figure 9. Scenario 1.

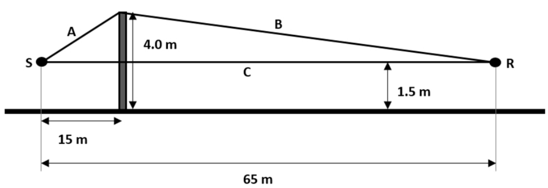

Figure 10. Scenario 2.

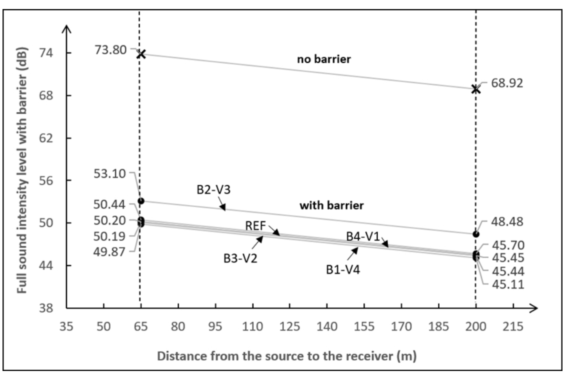

Figure 11. Total sound intensity levels in the scenarios adopted for 500 Hz.

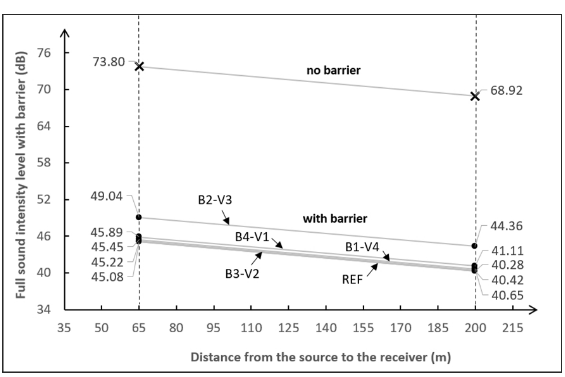

Figure 12. Total sound intensity levels in the scenarios adopted for 1000 Hz.

In this research, the concretes studied containing rubber and vermiculite were subjected to a test carried out in the impedance tube that determined the sound transmission loss. The results obtained are presented in Figures 4, 5, 6, 7 and 8, which show variations in sound transmission loss for different frequencies.

5. Conclusions

According to the results obtained in this study, it can be concluded that:

- All concrete mixes, except B2-V3 containing 20% rubber and 30% vermiculite, showed very similar values for the tests performed, both for the frequency of 500 Hz and for 1000 Hz.
- According to the specifications of DNIT 076[9], all the proposed traces can be used in concrete acoustic barriers, for the measured frequencies.
- For the frequency of 500 Hz, the concrete barrier (B1V4) containing 10% rubber and 40% vermiculite showed a reduction in the sound intensity level of 23.81 dB and 23.94 dB compared to the road without a barrier, for scenarios 1 and 2 respectively.

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