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NOISE ATTENUATION FROM TRAMWAY TRAFFIC

The article describes course and results of experiment, which provided influence of change of acoustic absorption properties of concrete tram track surface by using the recycled rubber on traffic noise attenuation. The experiment was carried out in cooperation of the Faculty of Civil Engineering, VSB-TU Ostrava with the companies: the Ostrava Transport Company Plc, ODS – the Transport Constructions Plc, INTERTECH plus, Ltd. and with the Faculty of Mechanical Engineering, VSB-TU Ostrava [2].

Keywords: *Sound absorption coefficient, concrete tiling panel, recycled rubber cover, traffic noise*

1. Introduction

In recent years, the Ostrava Transport Company has applied a number of noise elimination features that demonstrably reduce noise and vibrations from the tramway traffic. Nevertheless, a suitable element that would significantly reduce the level of noise in the construction of tram tracks with a cover (concrete tiling panels) has not been found yet. Hence it came the need to develop and validate such a track line cover that would produce better absorption properties and higher attenuation of emitted noise in comparison with existing covers (of reinforced concrete panels, asphalt concrete). At the request of the Ostrava Transport Company, the Faculty of Civil Engineering VSB-TU Ostrava conducted a two-year experiment whose aim was to test the influence of a change of acoustic absorption properties of the concrete tiling panel of tram track on the noise from tramway traffic [1].

2. Concept of modification of concrete tiling panel

Concrete tiling panel is one of the sound reflective materials. One of the possibilities to verify the influence of reflective surface of tram tracks on noise load generated by tramway traffic is to change the absorption properties of the concrete panel surface. Based on requirements of the Ostrava Transport Company, an option to improve the absorptive properties of the surface of the concrete tiling panel by the use of layers of recycled rubber was examined.

2.1 Properties of concrete panel

ODS – the Transport Constructions is the manufacturer of concrete panels (tiling). Concrete panels are rectangular 1240 × 1980 mm (type B – internal, inter-rail) and 1430 × 1980 mm (type C – external, inter-track). Longer sides are beveled so that the panel could follow the edge of the rail seating. The current height of panel is 170 mm. Panels are made of concrete C-/40 sap3b and reinforced by welded mesh reinforcement of 10 505 (R), ∅8/∅8 – 150/100 at the lower surface with a longitudinal lining pitch of 100 mm. The coverage on both surfaces is 45 mm. The panels are seated on the tram line ties with the pitch of 600 mm and can be loaded also by road transport (Fig. 1).

Due to the clearance zone of a tram car it was impossible to increase arbitrarily the height of the existing panel by an additional layer. A prerequisite for the realization of the modification was to reduce the height of existing concrete panel and its consequent topping by designed thickness of a rubber layer. The maximum thickness of the rubber layer was designed 40 mm. Given that the concrete inner panel is designed for the potential burden on road transport, it was necessary to execute a static computation of the change in the panel's height first.

Within the modification of the concrete panel, the way of mutual fusion between the rubber layer and concrete panel was also elaborated. The variant of sticking, which is commonly used, for instance, on concrete walls with acoustic absorbing coating consisting of a recycled rubber, was excluded. Due to the potential shear stress of the panel caused by vehicles' acceleration and braking forces, the variant of the treatment of contact surfaces of both materials was chosen in order to ensure better adhesion of the rubber layer to the substrate. This variant was also a subject of static computation.

Static assessment proved that weakening section of the panel will not affect its mechanical properties. It should, however, be considered the possibility of panel's damage during transport and assembly.

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2.2 Acoustic properties of boards made from recycled rubber

Recycled rubber is one of porous materials capable through its porous structure to absorb (consume) the incident acoustic energy. The absorption is expressed by ratio of sound energy that is absorbed during the impact and irreversibly transformed into heat to the total incident sound energy. Acoustic energy absorption occurs:

Fig. 1 Tramway track with concrete panels cover

- by multiple reflections of the sound beam in the pores of the material,
- by friction of air transmitting acoustic energy against the pore walls,
- by conversion of acoustic energy to the expansion work of periodically compressing air in the pores.

Quantity that expresses the ability of structure to absorb part of acoustic power of the incident sound wave is the sound absorption coefficient α [-] in a frequency band, defined as:

$$\alpha = \frac{W_a}{W_i} \tag{1}$$

where:
W_a is the acoustic power absorbed by material [W],
W_i is the net acoustic power incident on the material [W].

The sound absorption coefficient of the material depends on the relation of its thickness *d*, the frequency of the incident sound *f* and the pore size of material. Generally, at low frequencies the sound absorption coefficient increases with increasing thickness of the material. It attains its maximum at the thickness *d* when:

$$d = \frac{c}{4f} \tag{2}$$

where:
c is velocity of sound in air [m/s],
f is frequency of falling sound [Hz].

The goal of the experiment was to verify the optimal thickness and shape of the surface, which would ensure maximum absorption of acoustic energy while providing adequate strength and durability of the material in given conditions.

The shape and size of the spatial surface layout of rubber plates are limited by the manufacturing production. The thickness of the rubber layer is limited by the clearance zone of a tram car.

Four variants of a design were carried out in order to achieve the optimal comparison of acoustic properties of various thicknesses and shapes of the upper surface layer of recycled rubber.

- variant A – rubber plate with smooth surface, thickness 20 mm,
- variant B – rubber plate with smooth surface, thickness 40 mm, with reduced edges to 20 mm,
- variant C – rubber plate with shaped surface - traverse waves, thickness max. 40 mm,
- variant D – rubber plate with shaped surface – spatial bulges, thickness max. 40 mm.

A greater durability is assumed for plates with smooth surface and greater sound absorption is assumed for the shaped surface plates.

Acoustic properties of all variants of the rubber plate shapes were verified on the basis of the sound absorption coefficient whose values were measured in a reverberation chamber. The test was performed by an accredited testing laboratory CSI, Inc. Zlin. According to the standard CSN EN 1793-1:1998, evaluation of the absorption effects is carried out on the base of the coefficient of sound absorption measurement in laboratory conditions stated in the standard CSN EN ISO 354:2003.

The measurement results of sound absorption coefficient of all investigated variants of the shape of the rubber layers are presented in Fig. 2.

Based on the evaluation of acoustic properties of all variants of rubber plates, one can conclude that the optimal solution appears to be the variant of C – plate with waves of maximum thickness of 40 mm, and the D variant – plate with bulges of maximum thickness of 40 mm, which absorbs the sound even at higher frequencies (around 1600 Hz). Reducing noise levels at higher frequencies is more favourable to the human organism, since these noises are perceived as more intrusive. Based on these observations the variant of D was selected from all the investigated variants as a pattern for the modification of concrete tiling and, consequently, for its further usage on the test section.

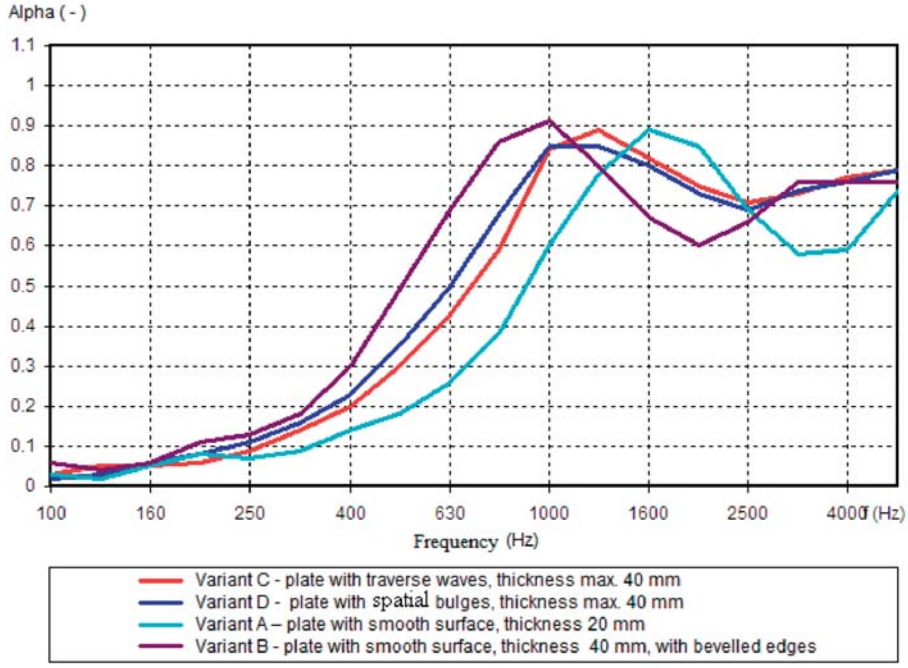

Fig. 2 Measured values of sound absorption coefficient of all examined variants of rubber plates

3. Implementation of the test section

A straight section of the two-lane tram track on Zavodni Street in Ostrava-Hrabuvka (see Fig. 3) was chosen as a test section to verify the properties of proposed modification of concrete tiling panel. The Zavodni Street is classified as collector, there are two-lane road (the width is 7.0 m), two-lane tram track (the width is 6.2 m) and two parking lanes (the width is 5.0 m). The tram track is separated from travel lanes by a physical barrier (concrete curb). The test section of the two-lane tram track is lined on both sides by a single-lane road, grass strips and fences of gardens of separate houses on one side, and by a fence of a town cemetery on other. The total length of the test section is 50 m.

Fig. 3 The test section of the tram line with modified tiling on Zavodni street in Ostrava

The exchange of panels took place in September 2008. The replacement of a tram line paving was carried out by the company DPO, Inc. The basic prerequisite for the final assessment of the impact related to the changes of the surface of panels on the noise level was the exchange of panels only, without any other noise feature elimination.

Existing panels were pulled out, the original sub-base was extracted to the ties and gravel bed. The geotextile separation layer was newly laid and covered by a sub-base from aggregate of fraction 0–4. Next, new panels were put in a bed. Filling of cement mortar was injected by a pump in order to minimize mortar spilling into the porous structure surface of panel.

4. Measurement of tramway traffic noise on test section

Noise measurement on the test section on Zavodni Street in Ostrava-Hrabuvka was carried out on 28 August and 8 October 2008. The first measurement was performed for the initial state of the tram track, the second, after the original tiling panels were replaced by the panels coated with a rubber layer (variant D).

The objective of the measurement was to verify the impact of the changes of absorption properties of tiling panels surface (coated with recycled rubber) on the noise from tramway traffic.

4.1 Principle of the noise measurement from tramway traffic

Noise measurements were conducted by the Department of Machine Parts and Mechanisms, Faculty of Mechanical Engineering, VSB-TU Ostrava [2]. Sound-level meter, type 2250B of firm Brüel&Kjaer was used for the noise measurement. Instant values of acoustic pressure pA [Pa], with frequency weighting A, were measured and recorded during the whole interval of passage of the reference tramway throughout the test section. A total length of recording of the acoustic pressure was $T = 8$ s. Records of each individual traversal were stored in computer memory with a sampling frequency of 10 kHz.

The sound-level meter was placed on a tripod in a horizontal plane at a height of 1.1 meters above the ground and surrounding terrain with no obstacles between the sound-level meter and the reference tramway during each of measuring sessions. The sound-level meter microphone was wind shielded by a soft PUR membrane.

Five passages of the reference tram (see Fig. 4) over the test section were measured at two tram speeds (40 a 50 km.h^{-1} $\pm$ 2 km.h^{-1}) and at two different distances between sound-level meter and the axis of measured track (7.5 a 15 meters). The tramway drove through the measured section by inertia, without acceleration pedal engaged.

In accordance with the Government Regulation no. 148/2006 Coll., on protection of health against the negative impacts of noise and vibrations, as amended, and the Methodological guidance for the measurement and evaluation of noise in non-working environment (RN. HEM-300-11.12.01-34065), the background noise in the idle state, before and after measurement, was also recorded. Its value was always about more than 10 dB lower.

The measurements always took place at night, from about 23.30 hours, when traffic on surrounding roads was very sparse. Only passages of the reference tram undisturbed by other traffic on the test section of Zavodni street were measured.

Fig. 4 Reference tramway

4.2 Evaluation of measurement results

From the recorded instantaneous value of acoustic pressure $p_{A,\,8s}$ the sound pressure level L_{Afast} [dB] was subsequently evaluated and the equivalent sound pressure level $L_{Aeq,4s}$ [dB] was computed from 15 highest values (in time interval of 4 s). Afterwards, the equivalent sound pressure level $L_{Aeq,4s}$ [dB] was evaluated as an average value of five records. The reference value of acoustic pressure $p_0 = 2.10^{-5}$ Pa.

Further, the amplitude spectrum (FFT) of representative records of acoustic pressure (without A-weighting filter) in the frequency bands from 0 to 5000 Hz and from 500 to 5000 Hz was evaluated in order to assess the effects of noise in terms of the ergonomic and hygiene criteria. In these frequency ranges the equivalent levels of sound pressure $L_{Aeq,4s}$ a $L_{Aeq,4s,cut}$ (equivalent level of sound pressure from the record of acoustic pressure with upper-pass filter of 500 Hz) were determined as well.

Table 1 and Fig. 5 represent the recorded results and their evaluation by two methods, by means of:

- the equivalent sound pressure level,
- the spectral analysis of sound pressure level (or acoustic pressure).

The equivalent sound level is a single-valued evaluation of noise related to the equivalent, maximal, or any other characteristic sound level for the given time interval. This classification is appropriate from the health perspective to assess the noise climate of living or working environment. However, a single value does not have sufficient explanatory power for the evaluation of acoustic properties of structures and is, therefore, not suitable for a separate assessment.

The spectral analysis of sound levels is a frequency analysis of sound level. It is suitable for technical evaluation of structures (for determination of significant frequency components and the design of appropriate protective measures). It is possible, by means of the spectrum of sound levels with a sufficient number of readings, to assess the frequency range at which the changes in the tram line construction will appear. These changes can be caused by the influence of inserted damping element or grinding the tram rails.

There was used a spectral analysis of the acoustic pressure in this paper, which is more accurate in the case of technical comparison of two states (in our case – panels with and without rubber layer). The conversion of the acoustic pressure in Pa to the sound pressure levels in dB causes proportional changes in the processed record. For our intention of technical comparison it was preferable to use the original measured values in Pa.

When comparing the measured single-valued values of the levels of sound pressure $_{LAeq,4s}$ we can see just a little impact of the

The resulting equivalent sound levels $L_{Aeq,4s}$ [dB] for frequency bands from 0 to 5000 Hz — Table 1

Transit speed of reference tramway [km/hour]	Initial conditions of tramway track		Conditions after exchange of modified panels with rubber layer	
	$L_{Aeq,4s\ cut}$ [dB]		$L_{Aeq,4s\ cut}$ [dB]	
	7.5 m from axis	15 m from axis	7.5 m from axis	15 m from axis
50	81.34	78.03	81.34	77.98

The resulting equivalent sound levels $L_{Aeq,4s\ cut}$ [dB] for frequency bands from 500 to 5000 Hz — Table 2

Transit speed of reference tramway [km/hour]	Initial conditions of tramway track		Conditions after exchange of modified panels with rubber layer	
	$L_{Aeq,4s\ cut}$ [dB]		$L_{Aeq,4s\ cut}$ [dB]	
	7.5 m from axis	15 m from axis	7.5 m from axis	15 m from axis
50	78.81	75.56	76.01	73.21

modified panels on the sound levels. Although during the actual measurement, a discernible decline of noise during passing of reference tram was audible. This effect is caused by the change of frequency pattern of noise levels due to changes of absorptive properties of the surface of tiling panel.

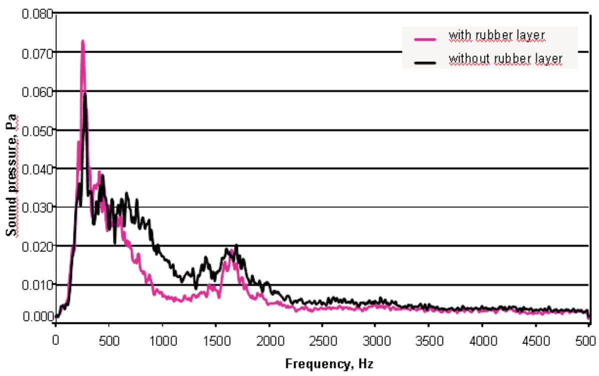

Fig. 5 Average spectra of sound pressure at the distance of sound-level meter of 7.5 m and reference tram passing speed 50 km.h^{-1} [2]

From the above chart of the average measured spectra of sound pressure is apparent noticeable decrease in sound pressure in the case of new modified panels. Absorptive properties of the top rubber layer are more apparent in the frequency ranges from 500 to 5000 Hz.

At low frequency ranges, the impact of changes in absorption capacity of panel surface is not reflected. On the contrary, the values of sound pressure appear to be higher than in the case of initial state. The reason for this probably lies in the fact that measurement of new layout took place shortly after deposition of new panels to the ballast.

In order to define more accurately the amplitude of attenuation of sound levels for new modified panels, the resulting equivalent sound levels $L_{Aeq,4s\ cut}$ [dB] for frequency bands from 500 to 5000 Hz only were assessed (Table 2). Further, the amplitude spectra (FFT) of sound pressure p_{Acut} [Pa] in the frequency bands from 500 to 5000 Hz were evaluated for representative passage records (Fig. 6).

When comparing the measured single-valued values of sound pressure $L_{Aeq,4s\ cut}$ in frequency range from 500 to 5000 Hz (which is the most perceptive range to the human ear), we can see a noticeable difference of measured levels of 2.2 to 2.8 dB between the initial tramway track layout and the new layout after panels being replaced. Such a difference is just perceptible to the human ear.

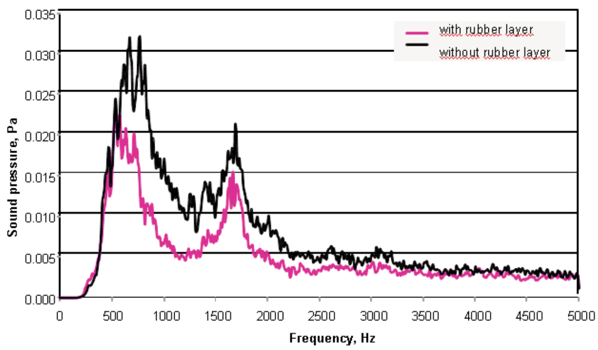

Fig. 6 Average spectra of sound pressure at the distance of sound-level meter of 7.5 m and reference tram passing speed 50 km.h^{-1} for frequency bands from 500 to 5000 Hz [2]

From the figure above there is an obvious significant decrease of the measured average spectra of the sound level in the case of newly modified panels, particularly in the frequency bands from 500 to 5000 Hz.

5. Conclusion

Based on the research and measurement we can conclude that the modification of surface absorption of the concrete tiling panel by using the recycled rubber can lead to reduction of the noise from tramway traffic. However, wider application of this system in practice will require further measures.

The positives, which the use of tiling panel coated by the recycled rubber will bring, can be summarized as follows:

- significant noise level reduction in the range of maximum sensitivity of human hearing, up to 2.8 dB,
- easy constructional replacement of existing panels by newly modified panels,

- still remains possibility of driving on the tram track for emergency vehicles, which have the right of way (and others, if necessary),
- easy tram track maintenance (during the winter period only a higher attention has to be required while working with a snow plow),
- short time of the technological implementation,
- availability of supplier, a good supplier-customer relationships.

But there are also some negatives:
- a failure to record attenuation of low threshold values of the noise (around 250 to 300 Hz),
- necessity of further investment for resolving the attenuation in the field of low threshold values of the noise,
- insufficient data to determine the final life-cycle of a new element (for now, after two years of operation without defects),
- drainage of rainwater,
- lack of data to determine the failure probability of the new element,
- a possible decrease of the absorption capacity of the panel caused by infiltration of dirt (unverified yet),
- higher implementation costs (currently the biggest obstacle to wider application).

References

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