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Research Paper

Side Effect of the Use of Acoustic Barriers Observed in the Infra Range

Andrzej STANIEK, Cezary BARTMAŃSKI*

Central Mining Institute
Department of Acoustics, Electronics and IT Solutions
Pl. Gwarków 1, 40-166 Katowice, Poland
e-mail: astaniek@gig.eu
*Corresponding Author e-mail: cbartmanski@gig.eu

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Acoustic barriers which are positioned along traffic lanes are designed to protect the surroundings from excessive noise. Such structures are to reverberate, diffract and damp the propagating acoustic waves. However, this method of shielding has some disadvantages which include constraint visibility and structure-born noise. The interaction between traffic-caused movement of air mass and acoustic barriers may generate infra noise waves. That is undesirable and should be estimated. The authors undertook the research to diagnose the plausible side effect of structure-born noise of such barriers because it may influence human body (Kasprzak, 2014). As a mechanical structure, the acoustic barrier is characterized by mechanical parameters which, in the field of modal analysis, are made up of natural frequencies, damping factors and mode shapes. In this paper the authors investigated the acoustic pressure distribution in the neighborhood of a real acoustic barrier in the scope of infra noise propagation. The methods of modal analysis were used to identify natural frequencies of the barrier and dominating frequencies of propagating waves in the far field. The correlation between observed vibration and acoustic signals is presented.

Keywords: modal analysis; infra range noise; vibration; acoustic barrier; road traffic.

1. Introduction

Methods of measurement and analysis may be divided into two types. One group is connected with direct acoustic field measurements and the other with structure mechanical parameters identification. Both have advantages and disadvantages. Accordingly, accessibility of the object under test is quite different. In the following paper two different methods of structural behaviour analysis are compared and correlation of results is discussed. One of the methods uses infra range acoustic microphones positioned in different points with one taken as the reference. The correlation of signals measured in different points and their power spectrums were calculated. The other is a classical modal analysis method (Remington, 1997), where measurement of vibrating structure – acoustic barrier was performed with the use of a laser scanning vibrometer. As the source of vibration both an impact hammer and road traffic environmental influence were utilized.

2. Field of interest

The aim of the research was to evaluate the magnitude of acoustic waves in the infra range and identify the source of generation of that signal near acoustic barriers. It is important to establish whether the propagating waves get to a point positioned behind a noise barrier as a secondary effect of vibrating surface of the shielding construction or they are generated by other sources positioned in the neighborhood of measurement points. There are many areas where researchers investigate the influence of infra range waves on human body, e.g. wind turbines (Carlile *et al.*, 2018). Also, reduction of continuous-cycle stationary low-frequency tone-like noise propagated through diffraction over a barrier border is limited (Borchi *et al.*, 2016). Accordingly, different methods to measure and analyze these phenomena have been incorporated (Degan, 2003; Serraris, 2016). The problem of reducing noise in low frequency range is well known and difficult to solve (Peiró-Torresa *et al.*, 2016). In this paper a comparison between vibration response of acoustic barriers and acoustic field measurements using low frequency range microphones is presented. These methods utilize modal analysis procedures and are used in order to realize the targeted study.

3. Methods

Three methods were used to measure the plausible effect of reverberated noise emission of acoustic barriers.

The first approach was based on measurements of vibration of the acoustic barrier, mainly the shielding surface, utilizing laser scanning vibrometer. The investigated acoustic barrier and distribution of measurement points are presented in Figs 1 and 2.

Fig. 1. The investigated noise barrier and distribution of measurement points.

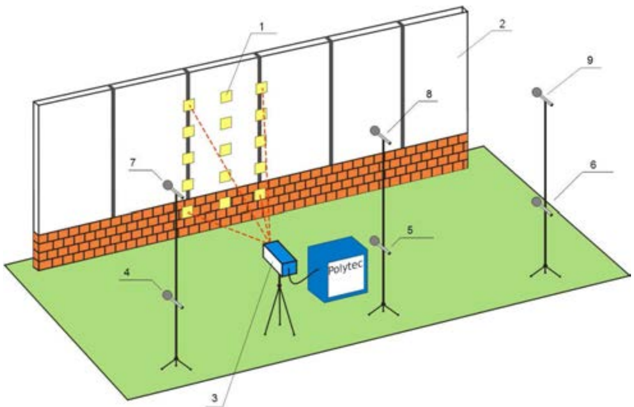


Fig. 2. The investigated acoustic barrier and distribution of measurement points.

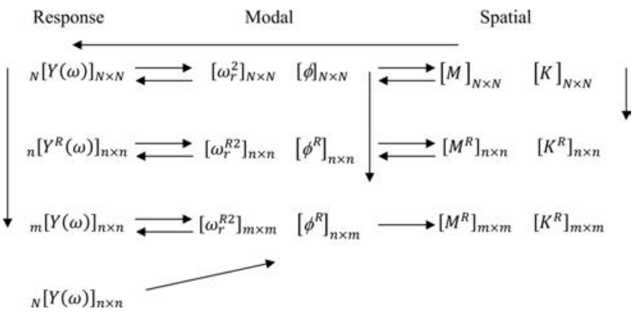
The second approach was based on both vibration and acoustic measurements, i.e. signals from two microphones positioned at the far field at a distance of 8 m behind the acoustic barrier were correlated with vibration signal from the reference accelerometer positioned at different places, shown in Fig. 1, on the shield – marked as 1, attached using glue mass, on the pillar – marked as 2, attached using an adapter plate, and near the ground – marked as 3, cemented to the bottom part of the fence. In all positions the vibrations were measured in the horizontal direction, perpendicular to the acoustic barrier.

The third measurement approach was a pure acoustic one with low frequency microphones localized at a distance of 8 m behind the acoustic barrier under test. The measurement points are shown in Fig. 2. There was one reference microphone localized at point 5 (at height of 1.6 m), and three rowing microphones positioned sequentially at points 4, 6, 7, 8, and 9 (at height of 1.6 m and 3.9 m). Additionally two points were localized close to the acoustic barrier at height 1.6 m and 3.9 m, positioned in the gap space of the investigated structure, not shown in Fig. 2. The scanning points are marked as 1, the investigated acoustic barrier as 2 and the laser scanning vibrometer as 3.

The measurements were performed using Polytec PSV-400 laser scanning vibrometer and Brüel & Kjær PULSE measuring system. In measurement chain PCB accelerometers type 393B12 and GRAS microphones type 40AN, and 40AZ were used. The results of these approaches were analyzed and compared.

4. Results

To describe a mechanical structure behaviour completely the following models may be used: a spatial model – represented by mass, stiffness and damping matrixes, a response model – consisting of all the frequency response functions for all degrees of freedom, and a modal model – covering all the mode shapes and natural frequencies. These models are equivalent to each other. In experimentally – based investigations it is almost impossible to match their accuracy. So we use reduced models, which means that the complete structural model of the investigated object of $N \times N$ matrix is related to $n \times n$ model of response matrix and $m \times n$ model of modal matrix, where $N \gg n > m$. General rules for relevance and adequacy of complete and incomplete models for the response, modal and spatial models are as follows (Ewins, 2000):



where letter N represents full dimension of analyzed model of the structure, n and m refer to the number of measured response functions and modal vectors respectively.

Moreover, as all the results were obtained using experimental modal analysis, in cases where both microphones and accelerometers were used, the reciprocity theorem condition was not fulfilled. Although it is one of the modal analysis basic assumptions, we must be aware that in such a situation it cannot be achieved for practical reasons. However, the aim of this study was not to give full description of mechanical behaviour and dynamic properties of the investigated structure as well as to describe its spatial model. The investigation was performed to show the correlation between different approaches to vibroacoustic measurements of the tested object and seemed to be adequate for scientific analysis.

The main purpose of investigations was to diagnose the propagating noise behind the acoustic barrier and to answer the question: what the source of that noise is, especially in the infra range and whether it is the effect of response of acoustic barriers to mechanical excitation. In Tables 1 to 9 the results of analysis performed for the aforementioned situations are presented.

Table 1. Comparison of the results of scanning method of two repeated measurements, the reference piezoelectric accelerometer attached to a pillar using stud and sticking mass.

Frequency 1	Frequency 2	Difference	Damping 1	Damping 2	Difference
9.77	10.20	0.43	0.43	0.53	0.10
12.12	11.95	0.17	0.65	3.29	2.64
16.19	15.95	0.24	0.04	1.75	1.71
16.71	15.95	0.76	0.05	1.75	1.70
27.90	–	–	0.20	–	–
33.28	33.28	0.00	0.04	0.03	0.01

Table 2. Comparison of the results of scanning method, a change of the reference piezoelectric accelerometer placement – on the pillar versus in the ground.

Frequency 3	Frequency 4	Difference	Damping 3	Damping 4	Difference
12.12	12.02	0.10	0.65	1.81	1.16
16.71	16.56	0.15	0.05	0.66	0.61
27.90	28.33	0.43	0.20	0.34	0.14
33.28	–	–	0.04	–	–

Table 3. Comparison of the results of a scanning method using laser vibrometer with piezoelectric accelerometer positioned on the pillar as a reference versus the results of measurement performed at the same time using 2 microphones positioned in the far field (approximately 8 m from the acoustic barrier) with the reference accelerometer positioned on the screen.

Frequency 5	Frequency 6	Difference	Damping 5	Damping 6	Difference
9.77	8.94	0.83	0.43	0.91	0.48
12.12	11.88	0.24	0.65	0.59	0.06
24.62	24.91	0.31	0.08	0.59	0.51
33.28	33.31	0.03	0.04	0.13	0.09

Table 4. Comparison of the results of a scanning method using laser vibrometer with piezoelectric accelerometer positioned on the pillar as a reference versus the results of measurement performed at the same time using 2 microphones positioned in the far field (approximately 8 m from the acoustic barrier) with the reference accelerometer positioned on the pillar.

Frequency 7	Frequency 8	Difference	Damping 7	Damping 8	Difference
9.77	10.36	0.59	0.43	0.09	0.34
12.12	12.05	0.07	0.65	0.08	0.57
16.71	16.22	0.49	0.05	0.10	0.05
24.62	–	–	0.08	–	–
33.28	33.29	0.01	0.04	0.09	0.05

Table 5. Comparison of the results of a scanning method using laser vibrometer with piezoelectric accelerometer positioned on the pillar as a reference versus the results of measurement performed at the same time using 2 microphones positioned in the far field (approximately 8 m from the acoustic barrier) with the reference accelerometer positioned in the ground.

Frequency 9	Frequency 10	Difference	Damping 9	Damping 10	Difference
9.77	9.24	0.53	0.43	1.06	0.63
12.12	11.46	0.66	0.65	0.17	0.48
16.71	–	–	0.05	–	–
23.45	23.39	0.06	0.24	0.18	0.06
27.90	27.02	0.88	0.20	0.10	0.10
33.28	32.88	0.40	0.04	0.06	0.02

Table 6. Comparison of the results of a scanning method using laser vibrometer versus the results of measurement performed at the same time using 2 microphones positioned in the far field (approximately 8 m from the acoustic barrier), in both cases the reference accelerometer positioned in the ground.

Frequency 11	Frequency 12	Difference	Damping 11	Damping 12	Difference
8.93	9.24	0.31	0.77	1.06	0.29
12.02	11.46	0.56	1.81	0.17	1.64
12.30	11.46	0.84	0.32	0.17	0.15
16.56	–	–	0.66	–	–
17.17	18.15	0.98	0.47	0.06	0.41
28.33	–	–	0.34	–	–

Table 7. Comparison of the results of measurement with microphones positioned at 6 points in the far field (approximately 8 m from the acoustic barrier, one of microphones used as a reference) versus the results of measurement performed using 2 microphones positioned in the far field (approximately 8 m from the acoustic barrier) with the reference accelerometer attached to the screen.

Frequency 13	Frequency 14	Difference	Damping 13	Damping 14	Difference
6.59	–	–	1.82	–	–
12.51	11.88	0.63	0.25	0.59	0.34
14.32	14.18	0.14	0.86	0.48	0.38
18.81	–	–	0.18	–	–
30.09	30.10	0.01	0.16	0.11	0.05
33.36	33.31	0.05	0.10	0.13	0.03
34.63	–	–	0.24	–	–

Table 8. Comparison of the results of measurement with microphones positioned at 6 points in the far field (approximately 8 m from the acoustic barrier, one of microphones used as a reference) versus the results of measurement performed using 2 microphones positioned in the far field with the reference accelerometer mounted on the pillar.

Frequency 15	Frequency 16	Difference	Damping 15	Damping 16	Difference
6.59	–	–	1.82	–	–
12.51	12.05	0.46	0.25	0.55	0.30
14.32	13.49	0.83	0.86	0.55	0.31
18.81	18.70	0.11	0.18	0.19	0.01
30.09	30.10	0.01	0.16	0.11	0.05
33.36	33.29	0.07	0.10	0.09	0.01
34.63	–	–	0.24	–	–

Table 9. Comparison of the results of measurement with microphones positioned at 6 points in the far field (approximately 8 m from the acoustic barrier, one of microphones used as a reference) versus the results of measurement performed using 2 microphones positioned in the far field with the reference accelerometer mounted in the ground.

Frequency 17	Frequency 18	Difference	Damping 17	Damping 18	Difference
6.59	–		1.82	–	–
12.51	12.85	0.34	0.25	0.41	0.16
14.32	13.70	0.62	0.86	0.37	0.49
18.81	18.15	0.66	0.18	0.06	0.12
30.09	–	–	0.16	–	–
33.36	33.28	0.08	0.10	0.13	0.03
34.63	–	–	0.24	–	–

We may group the following tables as comparison between:

- laser scanning measurements with reference point attached to different parts of the acoustic barrier,
- measurements of microphone signals with reference to a vibration signal measured at points placed on the acoustic barrier,
- measurements of microphone signals with reference to one microphone signal in the far field.

Additionally, to analyze results of those approaches more precisely, statistics tools were used and correlation as well as linear regression were calculated, as shown in Figs 3 to 7.

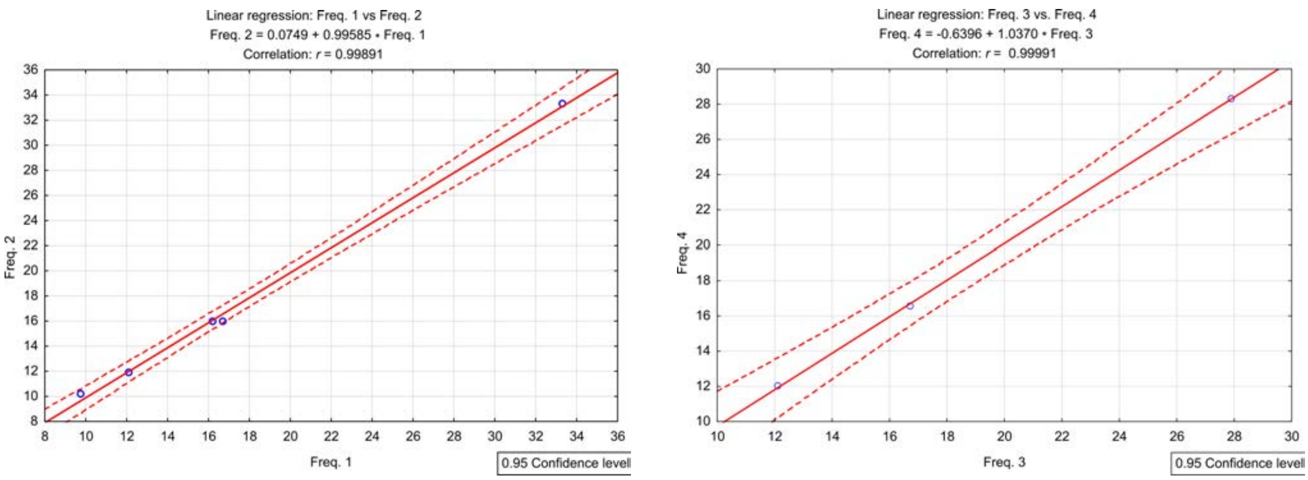


Fig. 3. Correlation and linear regression, Tables 1 and 2.

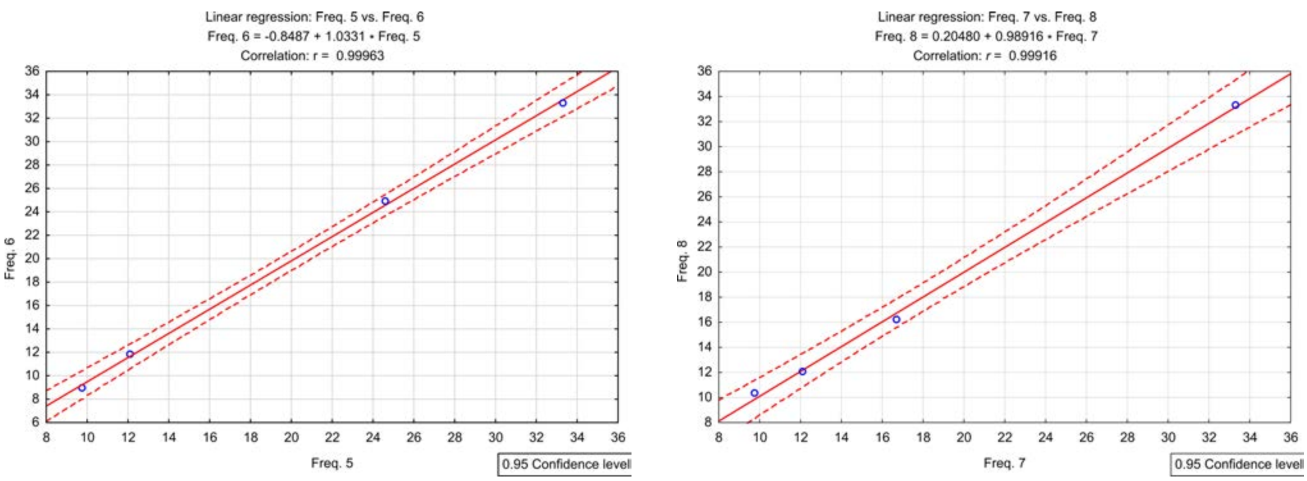


Fig. 4. Correlation and linear regression, Tables 3 and 4.

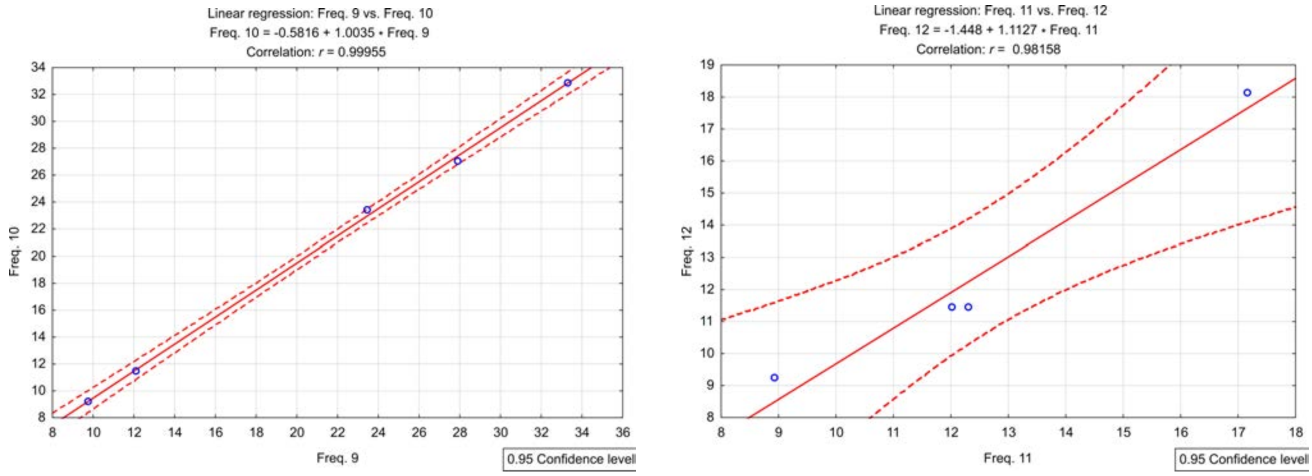


Fig. 5. Correlation and linear regression, Tables 5 and 6.

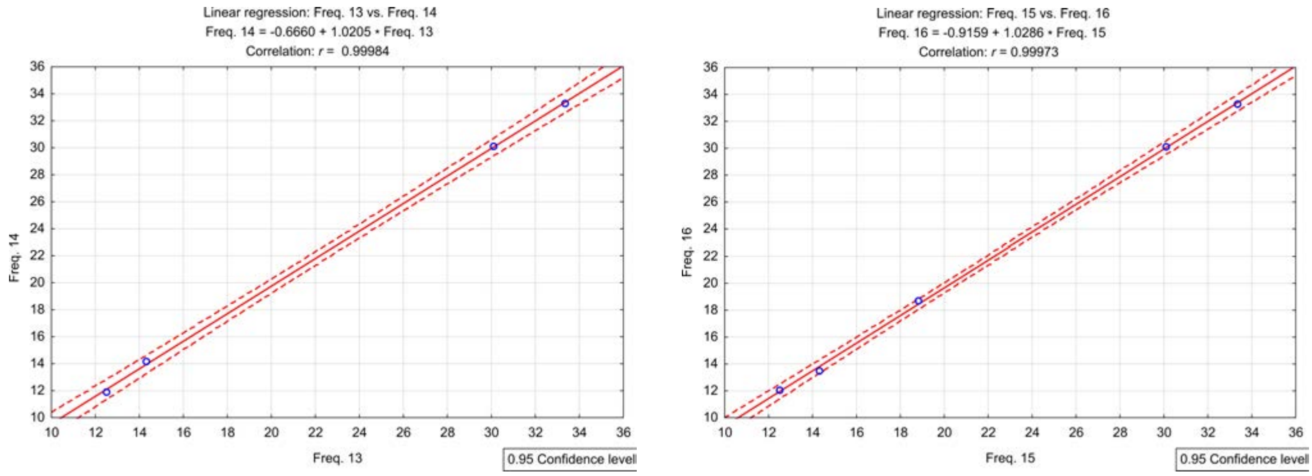


Fig. 6. Correlation and linear regression, Tables 7 and 8.

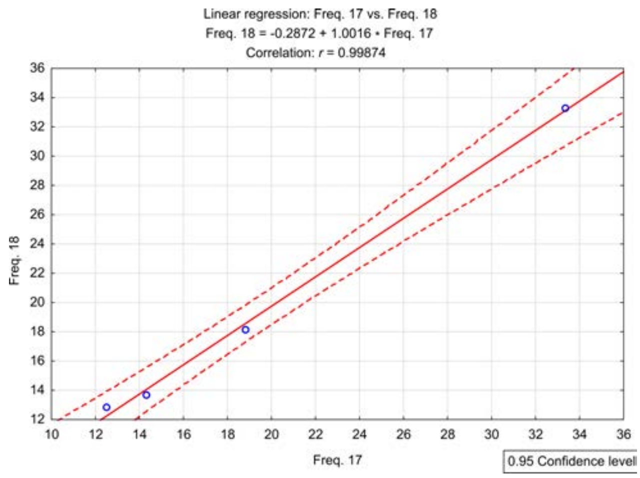


Fig. 7. Correlation and linear regression, Table 9.

In order to check the correlation between acoustic response (in the far field) and vibration excitation of the investigated acoustic barrier, the measurements and consequently modal analysis were performed using 2 microphones positioned in the far field (approximately 8 m from the acoustic barrier) with the reference accelerometer positioned in sequence on the screen, on the pillar and in the ground, shown in Fig. 1. That is not a typical use of modal analysis (see the comment above regarding the use of both microphones and accelerometers). These measurement results were compared with results taken from the scanning method – the comparison between the first and second type of measurements, aforementioned in the text. The results of comparison are presented in Tables 3–6 and in Figs 4 and 5.

Looking for relationships between the above results we have observed that in almost all cases, Tables 1 to 9, except Table 6, there are diagnosed modes of frequencies of about 12 Hz and 33 Hz (matched with green shadow colour). It implies that these modes are characteristic of both the analyzed acoustic barrier as well as of propagating acoustic waves, and consequently that these modes are excited by the acoustic barrier itself. For a frequency of about 16 Hz (marked out in blue shadow colour) we may imply that it is the mode characteristic of the pillar vibration, not observed in the remaining cases. The frequencies of about 14 Hz, 18 Hz and 30 Hz (marked out in orange shadow colour) seem to be generated by other sources positioned in the neighboring environment. Other modes may have more local character. The diagnosed frequencies are generally well correlated. In two cases the correlation is worse: Tables 6 and 9, where the comparison is made with measurement performed with 2 microphones positioned in the far field with the reference accelerometer mounted near the ground. That might be explained by the fact that there is a poorer correlation between reference accelerometer and microphone signals. It should also be mentioned that in some cases all frequencies could not have been detected so they are missing from particular tables. This might result from not exciting or measuring the corresponding frequencies. Considering that the results were obtained with the usage of different approaches of exciting the investigated structure to vibration as well as with different response and reference signals, we may infer that for frequencies of about 12 Hz and 33 Hz it is the inner feature of an acoustic barrier that causes such an effect, i.e. generates these frequencies in the infra range. The measured levels at low frequency range using microphones exceeded 70 dB and the recorded noise was generated mainly by heavy and long vehicles.

Figure 8 shows the waterfall diagram of one of the laser scan where the vibration of acoustic barrier under test was measured. Figure 9 presents the laser scanning vibrometer head and distribution of points of performed scan.

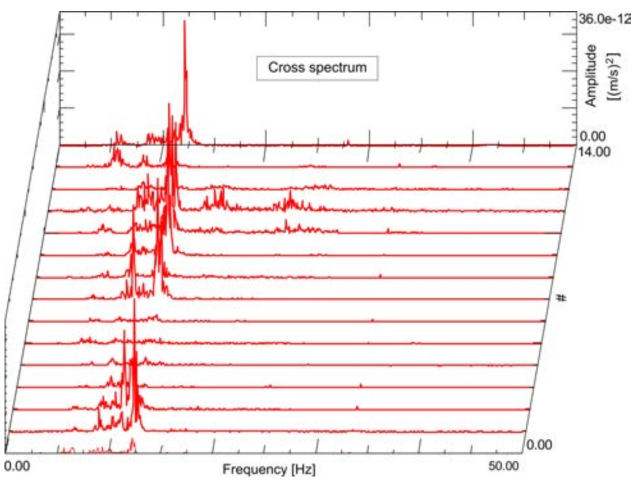


Fig. 8. Cross spectrum functions for operational modal analysis of the object under test.

Fig. 9. Laser scanning vibrometer and investigated noise barrier. Distribution of measurement points.

5. Conclusions

Taking into account the above results, we may imply that acoustic barriers generate acoustic waves in the infra range as a response to traffic transport, which is an undesirable side effect of reducing noise in a protected area. Though it is difficult to assess the impact of low frequency noise on human body, it influences citizens living in the neighboring area. The research made by Central Institute for Labour Protection (Kaczmarska *et al.*, 2008) revealed that infrasonic noise at workplaces in offices requiring employee's special attention focus cannot exceed 86 dB for 8 hours duration. Here the influence of analyzed phenomena is permanent and exceeding 70 dB, but not all diagnosed modes may be attributed to acoustic barriers as a source of infra range noise. Nevertheless, it is suggested the constructors should consider designing such protecting shields with resonant frequencies well above the infra range (Ishizuka, Fujiwara, 2003; Borchi *et al.*, 2016). Also the analysis for other types of acoustic barriers should be performed.

References

1. Borchi F., Carfagni M., Martelli L., Turchi A., Argenti F. (2016), Design and experimental tests of active control barriers for low-frequency stationary noise reduction in urban outdoor environment, *Applied Acoustics*, **114**: 125–135, doi: 10.1016/j.apacoust.2016.07.020.

2. Carlile S., Davy J.L., Hillman D., Burgemeister K. (2018), A review of the possible perceptual and physiological effects of wind turbine noise, *Trends in Hearing*, **22**: 1–10, doi: 10.1177/2331216518789551.

3. Degan A. (2003), *Acoustic barriers: performance and experimental measurements*, Tecniacustica, Bilba.

4. Ewins D.J. (2000), *Modal Testing: theory, practice and application*, Research Studies Press Ltd., Letchworth, Herts, England.
5. Ishizuka T., Fujiwara K. (2003), *Performance of noise barriers with various edge shapes and acoustical conditions*, Kyushu Institute of Design.
6. Kaczmarska A., Augustyńska D., Łuczak A. (2008), Infrasonic noise at workplaces in offices requiring employee's special attention focus [in Polish: Hałas infradźwiękowy na stanowiskach pracy wymagających koncentracji uwagi – propozycja kryterium uciążliwości], *Occupational Safety. Science and Practice*, **2008**(7–8): 28–32, http://archiwum.ciop.pl/28638.
7. Kasprzak C. (2014), The influence of infrasounds on the Sensory Motor Rhythm (SMR) of EEG Signal, *Forum Acusticum*, 7–12 September 2014, Cracow, Poland.
8. Peiró-Torres M.P., Redondo J., Bravo J.M., Sánchez Pérez J.V. (2016), Open noise barriers based on sonic crystals. Advances in noise control in transport infrastructures, *Transportation Research Procedia*, **18**: 392–398, doi: 10.1016/j.trpro.2016.12.051.
9. Remington P.J. (1997), Experimental and theoretical studies of vibrating systems, *Encyclopedia of Acoustics*, Vol. 2, John Wiley & Sons.
10. Serraris J. (2016), Propagation of sound around different noise barrier models using a three-dimensional scan based sound visualization technique, *Noise Control Engineering Journal*, **64**(2): 134–141, doi: 10.3397/1/376366.