EUROREGIO
BNAM2022
Joint Acoustics Conference
9th-11th of May, Aalborg, Denmark

Measurement of the acoustic effectiveness of diffractors

Fabio Strigari[*], **Ralf Becker, Wolfram Bartolomaeus**

Section Environmental Protection, Immissions, Federal Highway Research Institute, Bergisch Gladbach, Germany.

*strigari@bast.de

Abstract

One possible approach for innovative noise protection from road traffic noise is to use the diffraction principle to cause an upward diffraction of the sound. Technically, this involves periodic grid structures with resonance chambers of different depths. These produce a reduction effect that extends over a broadband frequency range. Diffractors can be embedded in the side space next to the road or mounted on a noise barrier.

In the present study, the acoustic effectiveness of two diffractor types was determined by means of controlled and statistical pass-by measurements. In order to ensure the best possible quantification of the noise reduction potential, the measurements were carried out on two times four microphones, simultaneously at the diffractor and at a reference. An equivalent noise barrier of the same height or the propagation over free field served as reference. The simultaneous measurements at the diffractor and the reference allow a direct comparison of the same emission source with almost identical emission strength and characteristic. The evaluation of the level differences shows a significant and height-dependent additional reduction effect by the diffractors. The analysis of the one-third octave bands illustrates the working principle of the diffractors and their optimisation for the road traffic noise spectrum.

In addition to classifying the acoustic effectiveness of the investigated diffractors, the general suitability of the measurement principle is also discussed. The results moreover provide an important input for possible approaches to consider diffractors in the calculation of sound propagation along roads, as presented at Euroregio/BNAM 2022 in the article "Simulation of the sound field behind diffractors".

Keywords: innovative noise protection, sound diffraction, pass-by measurements

1 Introduction

The possibility to reduce road traffic noise by exploiting the effect of diffraction has already been known for a long time in theory. For instance, in the EU-project HOSANNA (Holistic and sustainable abatement of noise by optimized combinations of natural and artificial means), conducted from 2009 to 2013, periodic grid structures with resonance chambers were discussed.

The working principle of such noise reducing devices is based on the upward diffraction of sound. A resonance of the sound waves occurs in the grooves of the diffractor. These grooves have different depths and are thus tuned to different frequencies, so that in total a broadband effect is created. The resonances create a change in impedance making the horizontally propagating sound waves experience a resistance and deflecting them upwards. The sound pressure level is thereby reduced at shallow angles of propagation, while it is increased at greater angles.

A first successful transfer of technology from theory to practical application is realized by the WHIS® product series of the Dutch company 4Silence, which allows to make use of the diffraction effect alongside roads and railways in situations where other mitigation measures cannot be realised or to reduce the necessary height of a noise barrier.

1.1 Description of the diffractor types under investigation

In the present study two types of diffracting elements were investigated, namely the so-called WHIS®stone and WHIS®wall.

The WHIS®stone is a structured concrete slab that is installed in the banquet next to the road. The dimensions of a single element are specified as 1020 x 980 mm with a height of 168 mm [1]. The weight is about 400 kg. The specified frequency range for noise reduction is 800 – 1200 Hz. The reduction of the sound pressure level for a single row installation is 2.5 dB according to the product description. For a double row arrangement (not examined here), the reduction is given as 4.0 dB.

The WHIS®wall is a combination of a low concrete noise barrier with a steel diffractor on top. Other material combinations are possible. The total structure is 1.11 m high and the maximum depth (given by the diffracting top) is 1.05 m [2]. The weight is about 1000 kg/m. The frequency range for noise reduction is given as 400 – 2000 Hz. According to product description, the achievable reduction of the sound pressure level is of the order of 7 – 9 dB, corresponding to the effect of a 3 m high noise barrier.

1.2 Existing studies

Measurements at the slab diffractor were carried out in 2013 and 2014 in the Netherlands, on the N 413 near Soesterberg and on the N 314 near Hummelo [3]. At distances of 7.5 m and 15 m from the closest lane in four different heights, sequential measurements were taken in the middle of three 100 m long sections (reference section, one and two diffracting rows), using the statistical pass-by (SPB) method. The results show a clear and significant upward bending of the sound. As expected, this leads to a sound reduction at low heights and to a sound increase at the higher microphone positions.

The diffractor wall was also experimentally examined in Soesterberg in 2019 [4]. Two microphone arrays, each consisting of four microphones, were used to determine the effect of the diffractor. The microphones were placed at heights of 1.2 m, 2.0 m, 3.0 m, and 4.0 m. Two measurement sections were considered: a reference section without any protection measure and a section with diffractor. Again, the SPB method was used, but both measurement sections were measured simultaneously (i.e. the pass-by of the same vehicle was recorded at both the reference and the diffractor). Although only a limited number of valid vehicles could be recorded, the results give a clear picture of the diffracting effect. In summary, the noise reductions recorded behind the diffractor (in a distance of 7.5 m) are $\gtrsim 9$ dB at 1.2 m height, ≈ 9 dB at 2.0 m height, $\gtrsim 6$ dB at 3.0 m height and $\gtrsim 3$ dB at 4.0 m height.

2 Measurements

Controlled pass-by (CPB) measurements took place at the "Technology Base" in Enschede, Netherlands. The site is located at Twente Airport. Two test tracks were available for the investigations. On one of the test tracks, the WHIS®stone is installed in a single row over a length of approximately 25 m, followed by a longer reference section with grassland. On the other test track, a WHIS®wall (1 m total height) over a length of about 50 m is installed. This is followed by a conventional noise barrier of the same height and on the other end by a longer reference section with grassland. Both test tracks are situated on flat ground and the width of the roadway is 2 x 3.5 m.

The measuring site for the SPB measurements was located along the federal road B 25 near Nördlingen, Germany. The 2 x 3.5 m wide roadway lies at an embankment and has a slight left curve leading away from a roundabout. In the 300 m long section, two 100 m long strips of the slab diffractor (single row arrangement) were installed, separated by a 100 m long area without modification of the banquet (reference section). In the front segment, the diffractor stones were rotated by 180°, in the rear segment the intended orientation (with the drainage facing the road) was used.

2.1 Measurement setup

The following figures show the measurement setup used for the pass-by measurements. For the investigation of slab diffractor, both for the CPB in Enschede and the SPB in Nördlingen, the pass-by level was determined at a distance of 7.5 m from the far lane (microphone positions M1 and M2) and at 7.5 m distance from the near lane (microphone positions M3 and M4) at a height of 1.2 m and 2.4 m above the level of the road (cf. Figure 1). The microphones were placed 15 m in front of and behind the transition between diffractor and reference section. The speed measurement system was located directly at the transition point. In contrast to the common right-hand traffic situation in the case of the SPB measurements, the same direction of travel was chosen for both lanes for the CPB runs (as indicated by the yellow arrows in Figure 1).

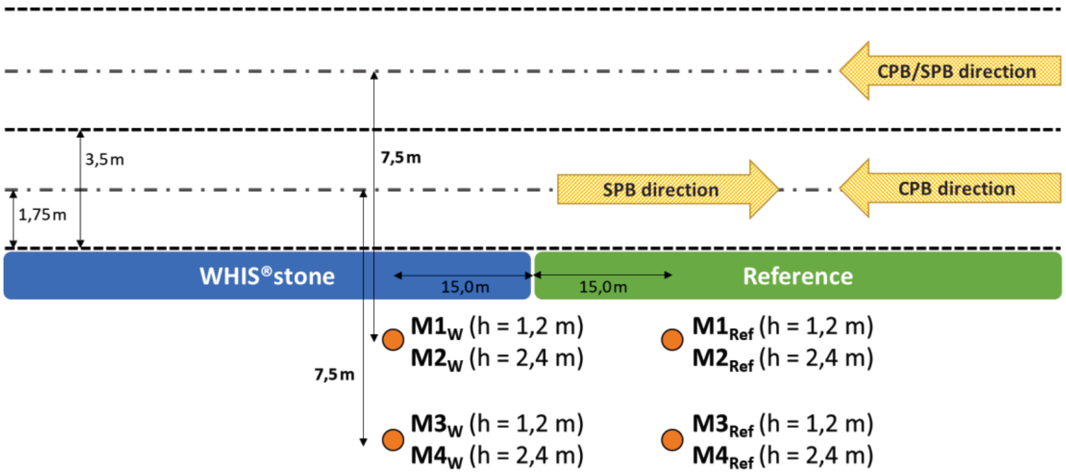

Figure 1: Measurement setup for the pass-by measurements on the slab diffractor (not to scale). Reference was free field sound propagation over grassland (ground reflections are not excluded).

The setup for the measurements at the diffractor wall differed slightly from the situation at the slab diffractor (cf. Figure 2). Here, one microphone was located directly between the first lane and the diffractor/reference (microphone position M1). Behind that, three microphones were situated at a distance of 5 m from the first microphone at heights of 1.2 m, 2 m and 3 m (microphone positions M2, M3 and M4). This choice was motivated, among other things, by the intention to achieve comparability with the measurement results from Ref. [4]. As above, the controlled pass-by always occurred from the same direction.

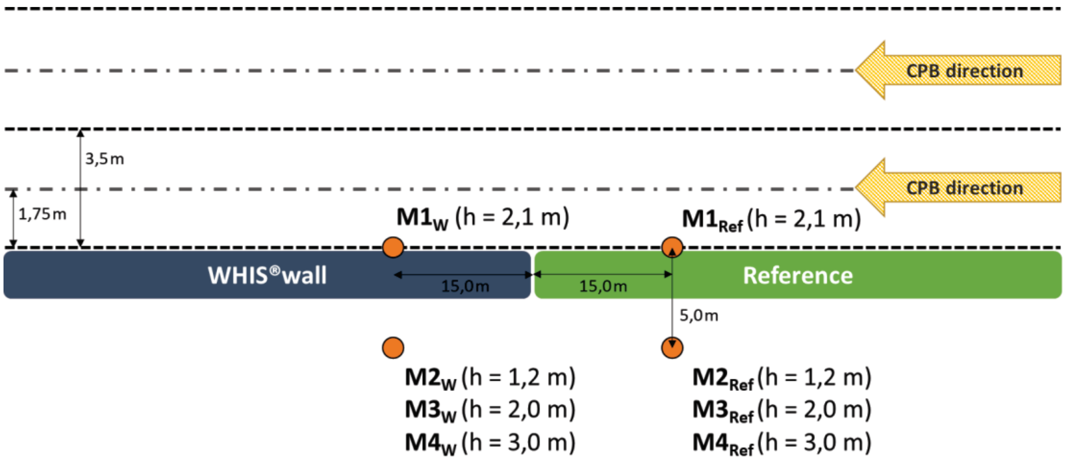

Figure 2: Measurement setup for the pass-by measurements on the diffractor wall (not to scale). Reference was free field sound propagation over grassland (ground reflections not excluded) and a conventional low noise barrier of the same height.

2.2 Measurement procedure

The CPB measurement campaign comprised three comparisons: slab diffractor vs. free field, diffractor wall vs. conventional noise barrier and diffractor wall vs. free field. The expression “free field” here is deliberately used for the reference sound propagation over grassland (ground reflections are not excluded). Each comparison consisted of 18 measurements (9 per lane) at speeds of 60 km/h, 70 km/h and 80 km/h (three measurements each). In all cases, the sound level of the same passing car was recorded simultaneously at both cross sections (i.e. diffractor and reference, distance to each other = 30 m).

Each time, the car was accelerated well outside the measurement cross-section and kept at the desired speed via automatic cruise control, so that at the moment of the pass-by always the same emission conditions prevailed (approximately). The speed and meteorology were also recorded. It was slightly cloudy and the wind speed was less than 5 m/s throughout the day. The air temperature was in the range of 19°C to 21°C.

The SPB measurement campaign was carried out on two days: one day the regular orientation of the diffractor stones was examined, on the second day the rotated version was investigated. Vehicles in both directions of travel were recorded. The free field sound propagation always served as reference. The pass-by sound levels of individual passing cars as well as light and heavy trucks were measured simultaneously at both measurement cross-sections. The data from the speed measurement system and the meteorology were fed into both measurement systems. These data include the passing speeds, the distance of the vehicles to the speed measurement system, wind speed and direction and air temperature.

On the first day, the active measurement time was about 6 h. It was cloudy and the wind speed was less than 5 m/s throughout the day. The air temperature was in the range of 15°C to 18°C. On the second day, the active measurement time was about 4.5 h. It was overcast and the wind speed was partly more than 5 m/s from midday onwards, so that single SPB runs had to be dropped as invalid. The air temperature ranged from 14°C to 19°C.

3 Results

In all pass-by measurements, the A-weighted individual sound levels of the respective measurement cross sections were determined simultaneously at the time of the maximum level at the loudest microphone position. For this point in time, also the third-octave band spectra were recorded and stored for further evaluation.

At the test tracks for the CPB, the signal-to-background ratio met the 10-dB criterion in all runs. The surrounding was very quiet, so that background noise played almost no role. The SPB results were analysed by first assigning the raw data of the respective cross sections to each other via measurement time, speed and distance. Implausible measurements and those that did not fulfil the 6-dB criterion (regarding the acoustic separation of two successive vehicles) were discarded.

To quantify the acoustic effectiveness of the investigated diffractors, the sound level differences $\Delta L1_{max,i}$, $\Delta L2_{max,i}$, $\Delta L3_{max,i}$ und $\Delta L4_{max,i}$ (running index i) between the corresponding microphones on diffractor and reference are calculated. The level differences are also determined for the recorded one-third octave bands (100 Hz to 20 kHz). The arithmetic mean is calculated for the total of n = 18 passings and for the vehicle passing on the near or far lane (n = 9) only. The empirical standard deviation is used as a measure of dispersion for the calculated mean values. The SPB data are analysed statistically by using common methods.

3.1 Slab diffractor

Figure 3(a) and (b) show the measured level differences [slab diffractor – reference (free field)] for the CPB on the near and far lane as box plots. The number of evaluated passings for one lane is n = 9. Each box represents one of the microphone positions, as depicted in Figure 1. Table 1 summarises the corresponding mean values and standard deviations.

The level reduction at position M1 (front-bottom, h = 1.2 m) is significant compared to the free field reference. On average, it amounts to -1.7 dB for the vehicle passing on the near lane and -1.4 dB for the far lane.

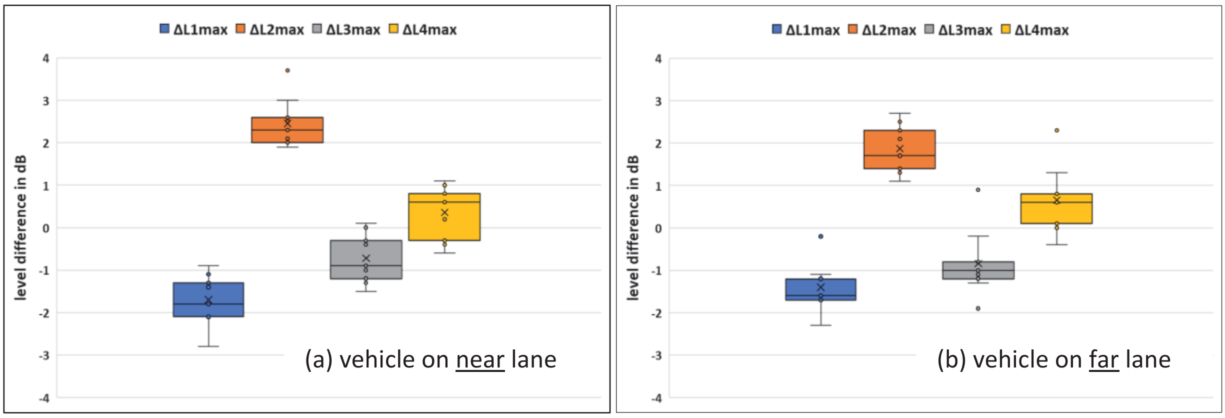

Figure 3: Box plots of differences of maximum CPB sound levels [slab diffractor – reference (free field)] in dB for the vehicle passing (a) on the near lane and (b) on the far lane at the microphone positions M1, M2, M3 and M4

Table 1: Mean values $\Delta\bar{L}i_{max}$ and standard deviation σ of the CPB level differences [slab diffractor – reference (free field)] in dB at the microphone positions M1, M2, M3 and M4; averaged over vehicles passing on the near lane, the far lane and over all lanes.

	$\Delta\bar{L}i_{max}$ **near**	σ	$\Delta\bar{L}i_{max}$ **far**	σ	$\Delta\bar{L}i_{max}$ **all**	σ
M1	-1.7	0.6	-1.4	0.6	-1.6	0.6
M2	2.5	0.6	1.9	0.6	2.2	0.6
M3	-0.7	0.7	-0.8	0.6	-0.8	0.8
M4	0.4	0.7	0.7	0.7	0.5	0.8

At M3 (rear-bottom, h = 1.2 m) a level difference of -0.7 dB (near) and -0.8 dB (far) can be observed. On the contrary, front position M2 at h = 2.4 m shows a significant level increase, namely 2.5 dB and 1.9 dB for the near and far lane, respectively. At the rear-top position M4, the detected level increase is only about 0.5 dB. The measurements generally show a good reproducibility and the standard deviation for all mean values is of a similar order of magnitude (0.6 dB to 0.8 dB).

The measurement results clearly illustrate the working principle of the diffractor. The sound energy is "redistributed" from bottom to top, so that a level reduction occurs for low emission angles, while the sound level increases accordingly for high emission angles. Averaged over all measurements (see Table 1), the maximum reduction effect at the lower height amounts to -1.6 dB.

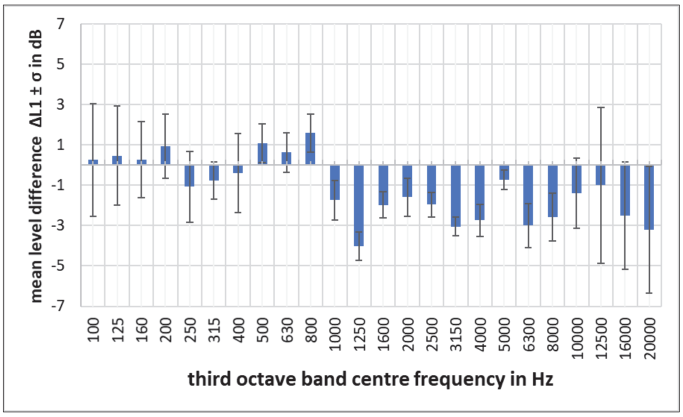

Figure 4: Mean value and standard deviation of spectral differences of maximum CPB sound levels [slab diffractor – reference (free field)] in dB for vehicle passing on the near lane at M1

The frequency dependence of the level differences (third-octave band analysis) is shown in Figure 4 for the front-bottom microphone M1 and passings on the near lane. The reduction effect of the diffractor is mainly effective in the frequency range above 800 Hz. Regarding the distant lane, the reduction already starts above 500 Hz (not shown), but – as expected – somewhat less pronounced. At measurement position M2 (front-top), a corresponding effect becomes evident in the opposite direction: for most frequency bands and especially above 800 Hz, a level increas occurs, i.e. the upward deflection of the sound is also noticeable here.

It is also worth mentioning that significant level reductions were also measured at the upper microphones M2 and M4 in the third-octave bands of 630 Hz and 800 Hz (approximately 2 to 3 dB).

In general, all trends and statements concluded above from the CPB measurements are confirmed by the results of the SPB measurement campaign at Nördlingen. Figure 5 shows the level differences [slab diffractor – reference (free field)] for passenger cars on the near lane as violin diagrams: The black cross indicates the mean value $\Delta\bar{L}i_{max}$, the white circle indicates the median ("P50") of the distribution. The blue box represents the range from the first ("P25") to the third quartile ("P75"), containing 50 % of all data. The red lines draw the range of the 5 % quantile ("P05") to the 95 % quantile ("P95"). 90 % of all data lie in this range. In Figure 6 the same representation is used for the data resulting from heavy trucks passing on the near lane.

The number of valid vehicles was well above 100 in both cases. At the positions M1 and M3, the mean level reduction compared to the reference is 2.3 dB and 5 dB, respectively. The mean level increase at the position M2 amounts to 2.1 dB. At the position M4 the level increase is only 0.3 dB. The significant level differences are lower in absolute value by up to 0.1 dB with respect to the respective mean values (statistical significance level = 0.05).

The statements obtained for passenger cars tend to remain valid for heavy trucks (and for light trucks as well, not shown here). However, the diffractor has a somewhat lower effect on trucks than on passenger cars. The mean level reduction at M1, for example, is only 0.8 dB for heavy trucks. Likewise, the level increase at the position M2 is also lower. For heavy trucks, the value there is 1.3 dB.

Table 2 summarises and compares the SPB results for passenger cars, light and heavy trucks. Both the level reductions and the level increases – resulting from the SPB data – are significantly lower for the far lane. This is also in agreement with the findings from the CPB measurements.

As explained in 2.1 and 2.2, on the second day of the SPB measurement campaign a rotated installation of the slab diffractor was investigated. The diffractor stones were rotated by 180° in this alternative arrangement. The resulting level differences (not shown here) are quite similar. What is striking, however, is the difference at the front-bottom position for passenger cars passing on the near lane. Instead of -2.2 dB in the normal arrangement, with the rotated diffractor stones the measurements yield only -1.0 dB level difference compared to the reference (free field).

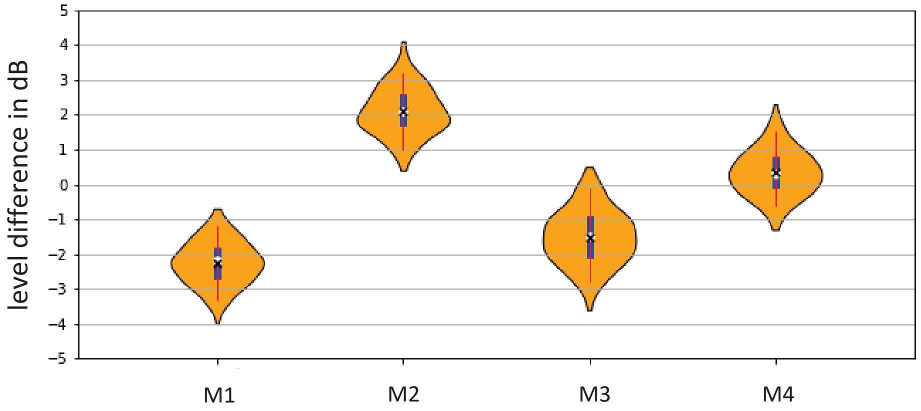

Figure 5: Violin plots of differences of maximum SPB sound levels [slab diffractor – reference (free field)] in dB for passenger cars passing on the near lane at the microphone positions M1, M2, M3 and M4

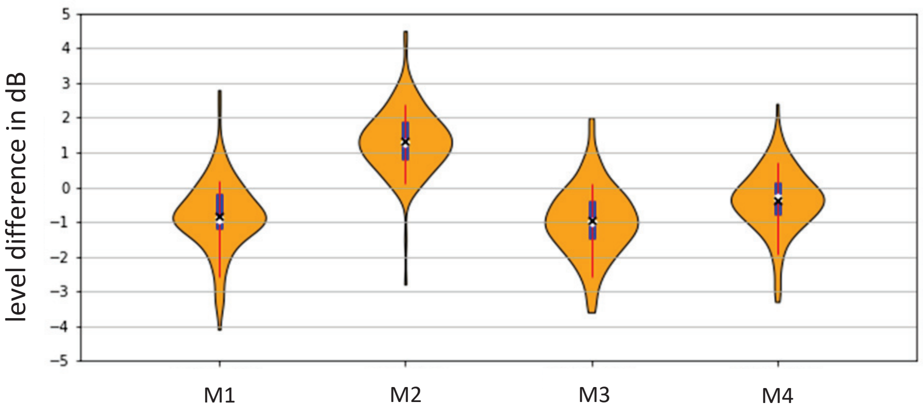

Figure 6: Violin plots of differences of maximum SPB sound levels [slab diffractor – reference (free field)] in dB for heavy trucks passing on the near lane at M1, M2, M3 and M4

Table 2: Significant level differences [slab diffractor – reference (free field)] in dB for passenger cars, light and heavy trucks in the near and far lane at the measurement positions. The last row gives the number N of valid vehicles used in the statistical analysis.

	near lane			far lane		
	passenger cars	light trucks	heavy trucks	passenger cars	light trucks	heavy trucks
M1	-2.2	-0.8	-0.7	-0.7	-0.1	-0.6
M2	2.0	1.4	1.2	1.4	1.2	0.7
M3	-1.5	-0.6	-0.9	-0.2	0.0	-0.5
M4	0.2	0.3	-0.3	0.3	0.2	-0.1
N	158	39	152	46	17	115

3.2 Diffractor wall

Figure 7(a) and (b) show the measured level differences [diffractor wall - reference (noise barrier)] for the CPB on the near and far lane as box plots. The number of evaluated passings for the near lane is n = 10, for the far lane n = 9. Please note that the measurement positions differ from the setup at the slab diffractor (cf. Figure 2). In Table 3 the corresponding mean values and standard deviations can be found.

Microphone M1 is located directly at the first lane in front of the diffractor. Here, the measured level differences vanish within the measurement accuracy, i.e. the emission levels at the diffractor and the reference noise barrier match as expected. At a height of 1.2 m and 2.0 m (M2 and M3), a considerable level reduction can be observed behind the diffractor compared to the reference. Since the total height of the diffractor wall and the reference noise barrier are the same, the measurement reflects the additional reduction effect coming from the diffractor. The values are -5.3 dB and -3.9 dB at M2 and -4.4 dB and -2.1 dB at M3 for the near and far lane, respectively (see also Table 3). Again, the height dependence of the level reduction is clearly recognisable. At h = 3.0 m, the reduction regarding the close lane is only -1.0 dB, and for the distant lane no reduction is measured any more ($\Delta L4_{max}$= 1.2 dB).

These CPB measurements also show a good reproducibility. The standard deviation is slightly higher for distant lane measurements at the two upper microphones M3 and M4 – thus, the degree of scatter of the individual measurements is somewhat greater here.

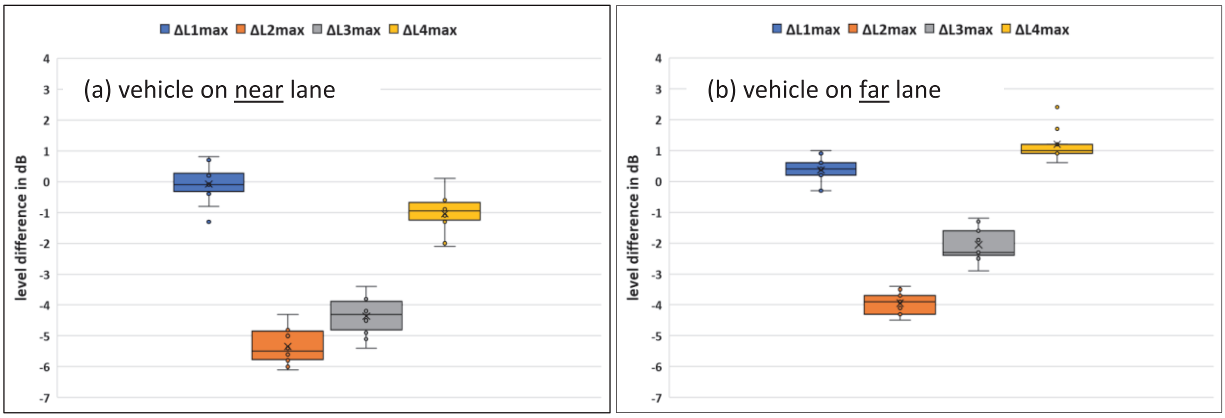

Figure 7: Box plots of differences of maximum CPB sound levels [diffractor wall – reference (noise barrier)] in dB for the vehicle passing (a) on the near lane and (b) on the far lane at the microphone positions M1, M2, M3 and M4

Table 3: Mean values $\Delta\bar{L}i_{max}$ and standard deviation σ of the CPB level differences [diffractor wall – reference (noise barrier)] in dB at the microphone positions M1, M2, M3 and M4; averaged over vehicles passing on the near lane, the far lane and over all lanes.

	$\Delta\bar{L}i_{max}$ **near**	σ	$\Delta\bar{L}i_{max}$ **far**	σ	$\Delta\bar{L}i_{max}$ **all**	σ
M1	-0.1	0.6	0.4	0.5	0.1	0.6
M2	-5.3	0.6	-3.9	0.4	-4.7	0.9
M3	-4.4	0.6	-2.1	1.1	-3.3	1.3
M4	-1.0	0.7	1.2	0.9	0.0	1.3

The third-octave band analysis of the level differences is shown in Figure 8 for M2 (h = 1.2 m) and close passings. The spectral range of the reduction effect of the diffractor is rather broad. Except for 315 Hz and 400 Hz, a level reduction is measurable in all third octave bands. The greatest effect can be seen in the range between 630 Hz and 1250 Hz (more than 7 dB for 630 Hz and 800 Hz). The results for the higher microphone M3 show a similar behaviour, but in a somewhat weaker form (not shown). Here, the largest detected reduction of -5.9 dB is in the 800 Hz band. Especially at the highest microphone M4 for the vehicle passing on the distant lane, there are also frequency-dependent level increases (not shown).

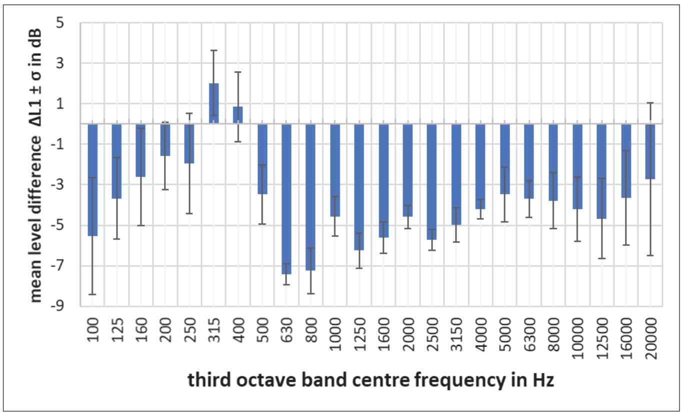

Figure 8: Mean value and standard deviation of spectral differences of maximum CPB sound levels [diffractor wall – reference (noise barrier)] in dB for the vehicle passing on the near lane at the microphone position M2

The results of the CPB at the diffractor wall in comparison to free field as reference are summarised in Table 4. The measured level differences are a measure for the total insertion loss of the diffractor wall (i.e. shielding plus diffraction effect). In agreement to the measurements befor, there is a clear height-dependent level reduction behind the diffractor. The maximum effect at M2 (at a height of 1.2 m) amounts to -15.3 dB for the near lane and -12.3 dB for the far lane. With increasing height (M4), the detected level reduction decreases to 5.1 dB (near) and 0.2 dB (far).

Table 4: Mean values $\Delta\bar{L}i_{max}$ and standard deviation σ of the CPB level differences [diffractor wall – reference (free field)] in dB at the microphone positions M1, M2, M3 and M4; averaged over vehicles passing on the near lane, the far lane and over all lanes.

	$\Delta\bar{L}i_{max}$ **near**	σ	$\Delta\bar{L}i_{max}$ **far**	σ	$\Delta\bar{L}i_{max}$ **all**	σ
M1	0.5	0.5	0.1	0.5	0.3	0.5
M2	-15.3	0.5	-12.3	0.4	-13.8	1.6
M3	-11.8	0.7	-6.1	0.7	-9.0	3.0
M4	-5.1	0.4	0.2	0.8	-2.4	2.8

3.3 SEL analysis

In a further analysis routine, the sound level over time is considered to calculate the sound exposure level (SEL). For this purpose, a fixed aperture angle of 120° is assumed. The SEL is equivalent to the sound energy reaching the respective microphones from this angular range. The corresponding time window is centred at the point in time of the maximum sound level. The windows size is of the order of 0.5 s – 2.3 s, depending on the pass-by velocity and the distance between the microphone and considered lane. This analysis approach is applied to the CPB data only, in order to assess the quality of the maximum sound level analysis.

Since the scope of the present manuscript is limited, only the resulting level differences [slab diffractor – reference (free field)] on the near lane are depicted in Figure 9. Qualitatively, the conclusions about the acoustic effectiveness of the diffractor remain the same as in the analysis via the maximum pass-by levels. However, when comparing to Figure 3, one can see (i) that the range of scatter of the SEL results is smaller, and (ii) that the mean level reduction at the lower microphones and level increase at the higher microphones become less in their absolute value. These two effects are observed also for the CPB measurements at the diffractor wall (not shown) and for passings on the far lane (not shown), whereas here the changes (ii) in the absolute values of the level differences are less prominent than on the near lane.

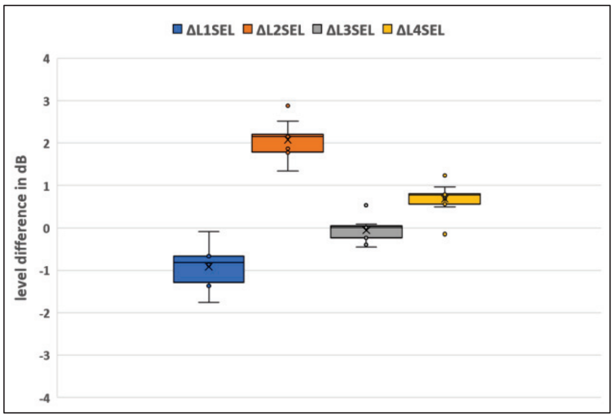

Figure 9: Box plots of differences of SEL sound levels [slab diffractor – reference (free field)] in dB for CPB on the near lane at the microphone positions M1, M2, M3 and M4

4 Conclusions

All CPB/SPB results indicate a significant acoustic effectiveness of the investigated sound diffractors. The reduction effect is generally lower for vehicles passing on the far lane than for a close pass-by. For the slab diffractor the level difference for low emission angles and at the microphones close to the road amounts to about -2 dB. According to the diffraction principle, an increase in the level difference (compared to free field) is detected at higher emission angles. For trucks the reduction effect turns out to be weaker than for cars.

The diffraction effect is also clearly evident in the CPB results for the diffractor wall. The combination of a low noise barrier with an attached diffractor shows a significantly higher acoustic effectiveness compared to the reference noise barrier of the same height. Additional level differences down to -5.3 dB are measured at 5 m from the first lane. Compared to the free field reference, level differences down to -15.3 dB are recorded.

The frequency dependence confirms the behaviour seen in the total level difference. Moreover, the one-third octave band analysis shows that the slab diffractor has its centre of action mainly in the frequency range above 800 Hz (or above 500 Hz for the distant lane). The effective frequency range of the diffractor wall is broader.

The differences between the SEL and maximum pass-by level analysis do not surprise from a physical point of view: The working principle of the diffractor is optimised for perpendicular sound incidence. Sound contributions reaching a receiver point from a certain aperture angle do not experience the same diffraction effect. Therefore, a superposition of sound coming from different directions leads to a weaker total effect. Nevertheless, considering the maximum pass-by levels still has a high validity, as contributions from angles close to perpendicular incidence are energetically dominant.

The measurement principle applied here has proven to be well-suited for the quantification of the acoustic effectiveness of sound diffractors. The simultaneous measurement of two cross sections allows a direct comparison of the same emission source with a well-defined reference and yields more meaningful and relevant results than doing a before-and-after measurement, which typically are prone to weather-related influences and traffic-induced differences.

Based on these promising measurements, the questions arise how the results can be used to draw conclusions about the acoustic effectiveness at greater distances and how the acoustic effect of diffractors can be considered in a more general calculation of sound propagation from roads. A first approach to do so has been realized by modelling the diffractors as a strip with a frequency-dependent acoustic impedance and using an impedance jump model for calculating the sound propagation. This is presented by Bartolomaeus *et al.* in the article "Simulation of the sound field behind diffractors" [5], which is kindly recommended to all interested readers.

Acknowledgements

I would like to thank the company 4Silence for the kind admission at its headquarters on Twente airport and giving us the possibility to carry out measurements on site.

References

[1] WHIS®stone product description. *https://www.4silence.com/whisstone/*, last access: March 07, 2022.

[2] WHIS®wall product description. *https://www.4silence.com/whiswall/*, last access: March 07, 2022.

[3] J. Hooghwerff, W. J. van der Hejiden, H. F. Reinink and Y. H. Wijnant. Whisstone, a sound diffractor: does it really affect traffic noise?. *Proceedings of EuroNoise 2015*, 2015.

[4] Y. H. Wijnant and Z. A. Lok. Metingen Soesterberg. *Measurement protocol University of Twente*, 2019.

[5] W. Bartolomaeus, R. Becker and F. Strigari. Simulation of the sound field behind diffractors. *Proceedings of Euroregio/BNAM 2022*, 2022.