VIENNA 2018 TRA
A digital era for transport
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Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Diffractors: a fascinating alternative to noise screens?

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Abstract

A recent invention by the University of Twente in the Netherlands – diffractors – might be an interesting alternative for noise screens for shielding certain areas from traffic noise. Diffractors basically consist of a series of slits in the ground or mounted on a low shield which are parallel to the road. The sound waves passing over the slits cause standing sound waves in them with a maximum amplitude on the edge, where they interact with the sound wave passing over, causing the sound energy to bend upwards. As each slit resonates at a particular frequency, a series of slits is foreseen with varying depths, each resonating at a different frequency, in order to deal with the broad band traffic noise. Numerical simulations by the inventors and measurements ordered by them look very promising and suggest that a device of about 0,5 m high and 1 m wide would have the same effect as a 4 m high noise screen. An independent team has been formed by the Belgian Road Research Centre and the Flemish Agency for Traffic and Roads which has done "Controlled Pass By" measurements with a car and a lorry at a prototype installation (diffractors on a low screen) along a secondary road in Losser near Enschede in the East of the Netherlands. One measured at different distances from the road. This contribution summarizes the findings of these measurements and gives an answer if diffractors are a valid alternative for noise screens or not.

Keywords: diffractor; traffic noise; noise abatement

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1. Introduction

A diffractor is a device recently developed in the Netherlands to abate road traffic noise (Hooghwerff 2014; Wijnant 2016; Hooghwerff 2015; Wijnant 2015). It consists of a number of slits with different depths installed along a road, parallel to its centre line. The sound waves generated by passing vehicles induce standing sound waves in the slits by resonance, with antinodes of those standing waves at the top of the slots. The standing waves interfere with the sound waves from road traffic passing over the diffractor and bend them upwards, thereby creating a "shadow" zone beside the road (on the right hand side in Fig. 1).

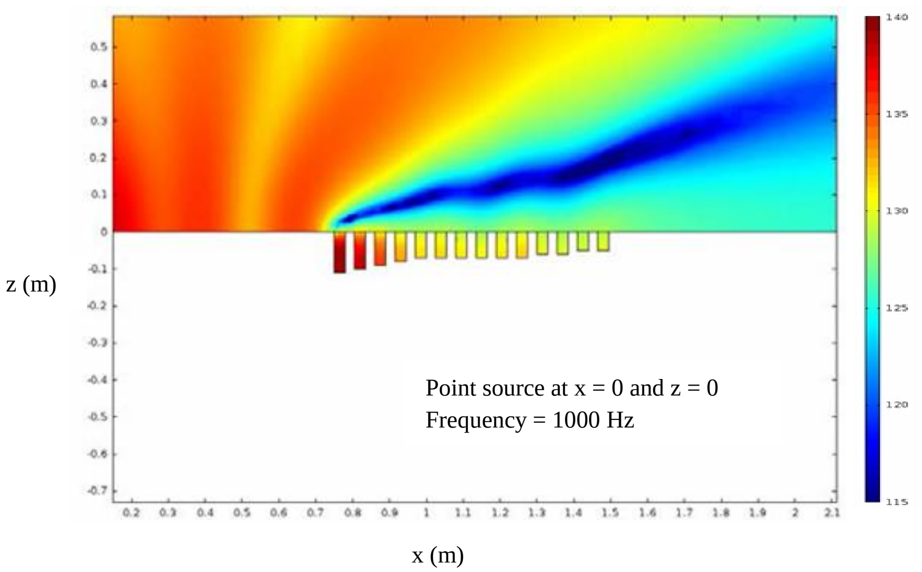

Fig. 1 Simulation of the effect of a diffractor consisting of a series of slits in the ground on SPL. (courtesy of Y. H. Wijnant, U Twente).

In practice slits with different depths are combined in order to obtain resonance at different frequencies in the relevant traffic noise spectrum. As such, they are a propagation measure that may provide an interesting alternative to conventional noise screens. Such screens are, indeed, expensive, intrusive, and sensitive to vandalism (such as graffiti). Computer simulations were made and experimental setups constructed on various sites in the Netherlands. The latter generally consisted of diffractors buried into the ground alongside the road and allowing a modest yet significant noise reduction of 3 dB. An interesting variant, however, is a diffractor on a low screen, which according to computer simulations is capable of yielding substantially higher noise reductions: up to about 9 dB.

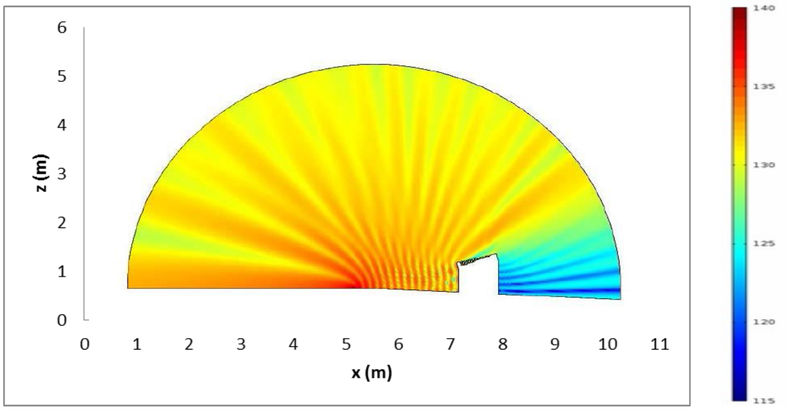

Fig. 2 Simulation of the effect of a diffractor on top of a low screen on SPL. (courtesy of Y. H. Wijnant, University of Twente)

2. The test setup with diffractors at Losser

The experimental setup alongside the N732 at Losser (Fig. 3) consisted in a cluster of various diffractors: one diffractor in synthetic material on a low screen over a length of 25 m (position 1 in Fig. 3) and one diffractor in corten steel – also on a low screen– over a length of 75 m (position 2 in Fig. 3). The height of the low screen + diffractor varies from 45 cm to approximately 60 cm. Starting from kilometre mark 3,300 another diffractor has been buried into the ground (position 3 in Fig. 3). Beyond the diffractor in corten steel there is a second type of diffractor buried into the ground (position 4), but this one is irrelevant to our measurements. Pictures of the devices are shown in Fig. 4; from left to right: the diffractor in synthetic material on a low screen (at position 1), the diffractor in corten steel on a low screen (at position 2) and the diffractor in corten steel on a low screen combined with a buried concrete diffractor (at position 3).

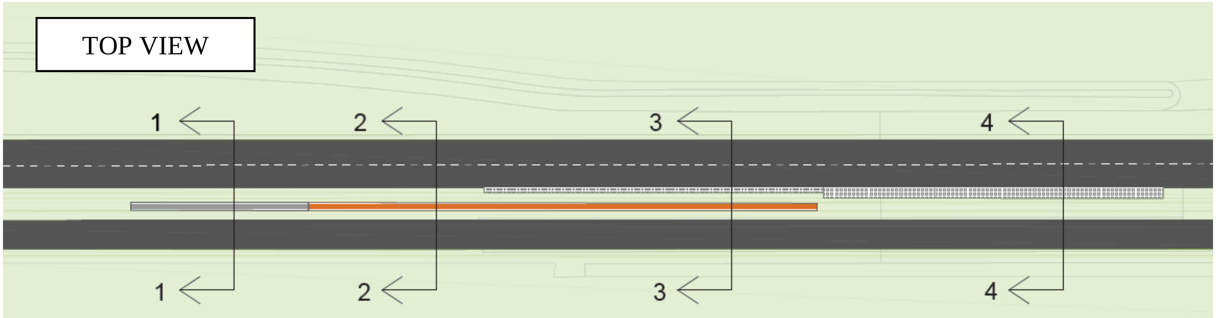

Fig. 3 Situation plan of all the diffractors at Losser (courtesy of B.J. Danker, 4SILENCE)

Fig. 4 The different types of diffractors

3. Controlled Pass-by measurements (Goubert, 2017)

Measurements were made by the not-standardised "Controlled Pass-by"(CPB) method, with (our own) test vehicles passing at a well-defined constant speed. The maximum sound pressure level in dB, with "A" frequency weighting and fast time weighting, was measured at a number of points behind the diffractor. A reference measurement was also made on a location somewhat further down the road, where there is no diffractor. Apart from that, the propagation path (ground absorption and reflection) on this reference location is similar.

To measure the effects of the low-screen diffractors, the microphone was placed off kilometre mark 3.300 at distances of 12 m, 30 m and 50 m, respectively, from the centre line of the traffic lane closest to the diffractor. The microphone was invariably positioned 1.2 m above the road surface. The reference location was chosen off kilometre mark 3,440, where measurements were made at the same distances from the centre line of the same lane and with the microphone installed at the same height (Fig. 5 and Fig. 6). It should be noted that on this reference location a house is standing on the opposite side of the road, with its triangular side wall turned to it. Ideally there should be no reflecting surface there, but it was impracticable to choose another reference location. The effect of reflection from that wall, may, however, be considered as very limited (see §4).

Fig. 5 View of the location for reference measurements

Fig. 6 View of the location for measurement points behind the diffractor

The surface course of the N732 is SMA 0/14 with limestone aggregate (left hand picture of Fig. 7). Visually speaking, the road surface appears to be in very good condition and very homogeneous. This homogeneity was verified by CPX (the right hand picture of Fig. 7). The CPX levels in blue are the ones measured on the lane along the diffractor and the orange ones are those on lane at the other side of the road. The green vertical line indicates the position of the measurement behind the diffractor and the red line shows the position of the reference measurement. Variations between the two measurement positions are minimal.

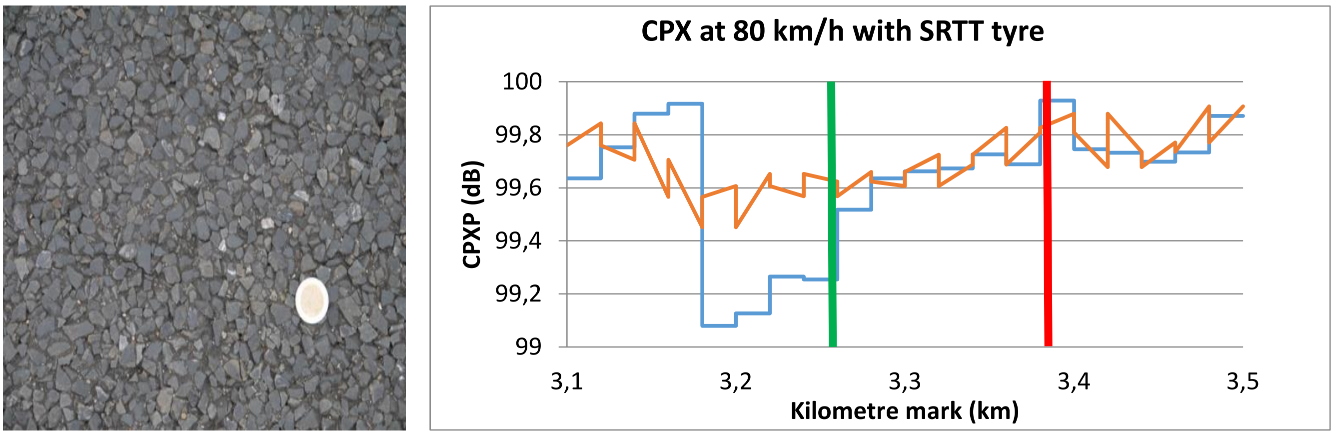

Fig. 7 The surface course of the N732 at the diffractors (left) and right the CPX-levels

The following test vehicles were used:

- one VOLVO S60 passenger car with a D3 diesel engine (2.0 l turbodiesel) and Vredestein type "winter xtreme" M+S 235/45 R17 winter tyres (Fig. 8, left hand side)
- one Mercedes 1827 lorry with Michelin type XZA2 Energy 315/70 R22.5 tyres on the front axle and Michelin type XDA2+ Energy 315/70 R22.5 dual tyres on the rear axle (Fig. 8, right hand side)

Fig. 8 VOLVO S60 passenger car (left) and Mercedes 1827 lorry used for the CPB measurements

The measurements were made at two speeds: 75 and 85 km/h with the passenger car (in order to see a possible influence of the speed), and 50 and 80 km/h with the lorry. The test vehicles were driven on the lane along the diffractors, but also on the lane in the opposite direction. To improve accuracy†, a number of "good" runs – at least seven, but often more in practice – were made for each combination of vehicle, speed, direction of travel, and microphone position. Moreover, the operators only considered the runs in which the test vehicles were sufficiently isolated from other vehicles when passing by the microphone. Measurements were carried on two days: 11^{th} of April 2017 and 3^{rd} of May 2017. Air temperature varied on the first measurement day between 12 and 23 °C and on the second day around 20°C. Wind speed was low on both days.

4. Results and analysis

4.1. Measurements with the passenger car

As stated before, several measurements of LA_{max} were performed per combination of vehicle, direction of travel, speed, and microphone position, and the mean value was calculated. The difference between the mean LA_{max} values behind the diffractor and on the reference location reflects the reduction owed to the presence of the diffractor. Fig. 9 shows noise reduction versus microphone position for the passenger car driven at 85 km/h <u>on the lane alongside the diffractor</u>. For the microphone position at 12 m, noise reduction for that vehicle driven at 75 km/h is represented as well. Two results are shown for the microphone position at 50 m: the result to the left was measured by AWV on 11^{th} April and that to the right by BRRC on 3^{rd} May.

Extreme noise reductions of 8 to 9 dB are found for the microphone positions at 12 and 30 m. The difference in speed between 75 and 85 km/h does not result in a significant difference in noise reduction. At the of 50-m point noise reduction drops to approximately 4 dB. This is still significant, but considerably less than closer to the road. The result measured by AWV at 50 m on 11^{th} April was confirmed by the measurement performed by BRRC on the additional measuring day of 3^{rd} May.

† That is, to reduce random error.

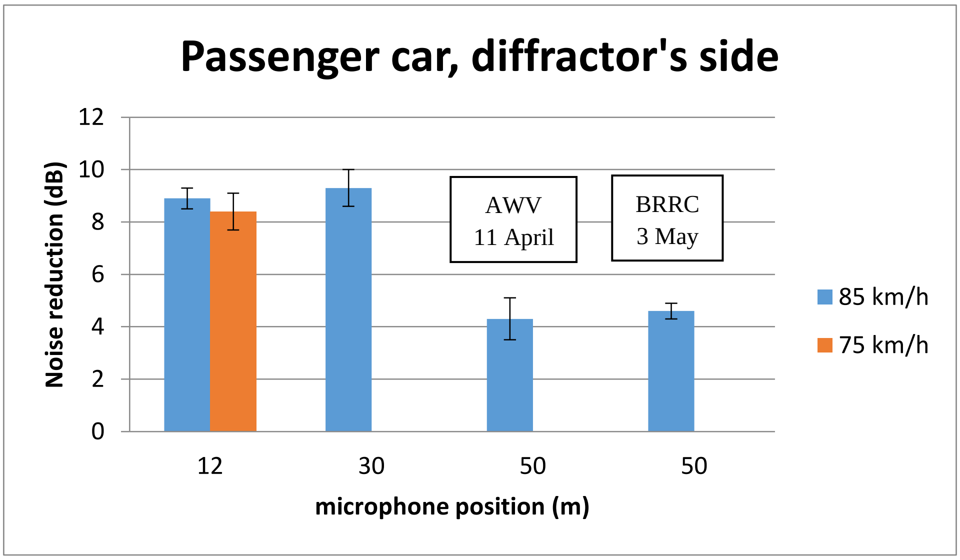

Fig. 9 Noise reductions by the presence of the diffractor, for a passenger car travelling on the lane alongside the diffractor

Fig. 10 shows the noise reductions measured for the passenger car travelling on the lane on the other side of the road. Substantial noise reductions of 6 to 8 dB are measured at 12 and 30 m. For both lanes, the difference between results at 75 km/h and 80 km/h are not significant. At the 50-m point, AWV measured a reduction of 4 dB on 11th April and BRRC a reduction of only 2 dB on 3rd May. The cause of this discrepancy is yet unclear. Different weather conditions may have played a part.

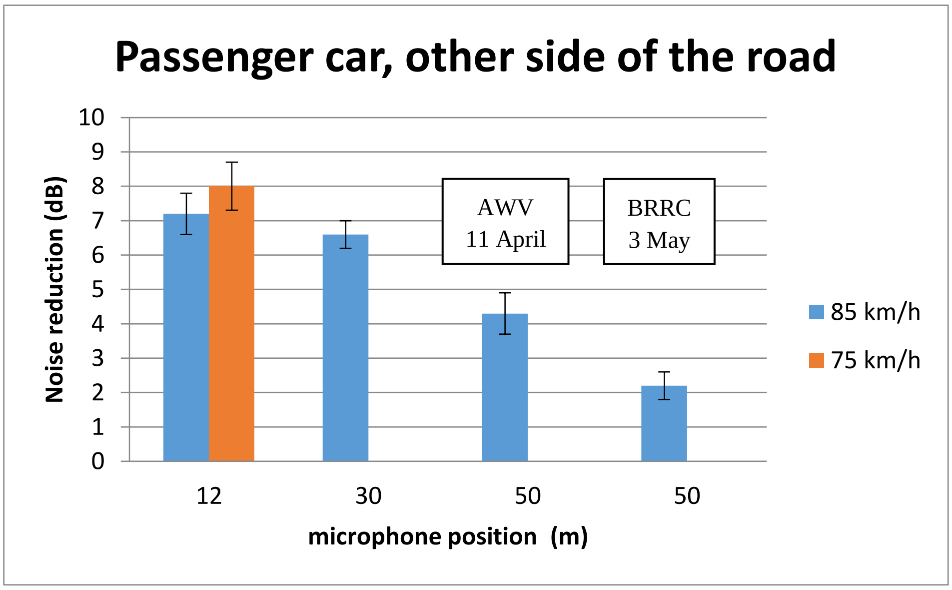

Fig. 10 Noise reductions by the presence of the diffractor, for a passenger car travelling on the lane on the other side of the road

4.2. Measurements with the lorry

Fig. 11 shows the noise reductions measured for the lorry driven on the lane alongside the diffractor. They are – not quite unexpectedly – a bit lower than for the passenger car and range from slightly below 5 to approximately 6.5 dB. Like for the passenger car, the reduction drops to a lower value, 3.5 dB, at 50 m. For the microphone position at 12 m, measurements were made at two widely different speeds, i.e., 50 and 80 km/h. The results show that the effectiveness of the diffractor does not depend upon speed – at least not in this range.

For the lorry travelling on the lane on the other side of the road, the diffractor is found to reduce noise by 6 dB at the distances of 12 and 30 m, again regardless of speed (Fig. 12). At 50 m, the reduction decreases to 3.5 dB according to the measurement by AWV on 11th April and to slightly below 2 dB according to the measurement by BRRC on 3rd May. So this remarkable discrepancy is found for the lorry as well.

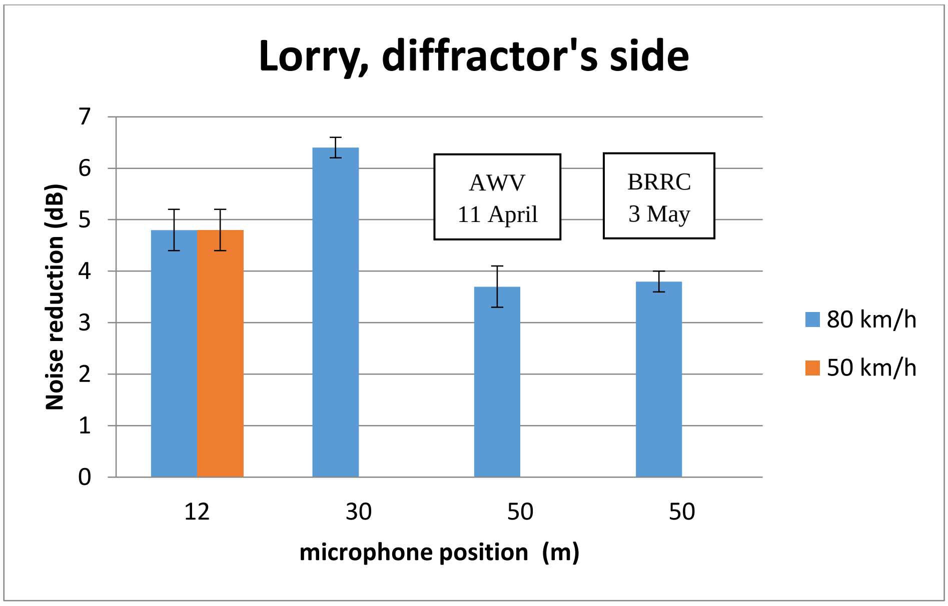

Fig. 11 Noise reductions by the presence of the diffractor, for a lorry travelling on the lane alongside the diffractor

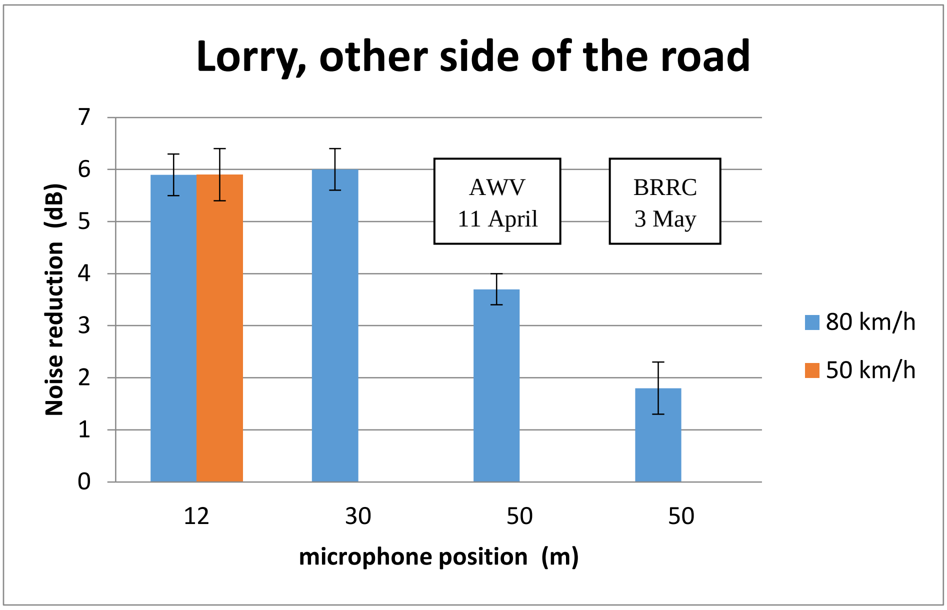

Fig. 12 Noise reductions by the presence of the diffractor, for a lorry travelling on the lane on the other side of the road

Fig. 13 shows the octave band spectra measured at 50 m from the road, on the reference location and at the diffractor. They all have been averaged over three runs of the passenger car at 85 km/h, but the uncertainty of the sound pressure levels in the respective octave bands remains considerable. Nevertheless, the results seem to suggest a broad-band influence (125 – 4,000 Hz).

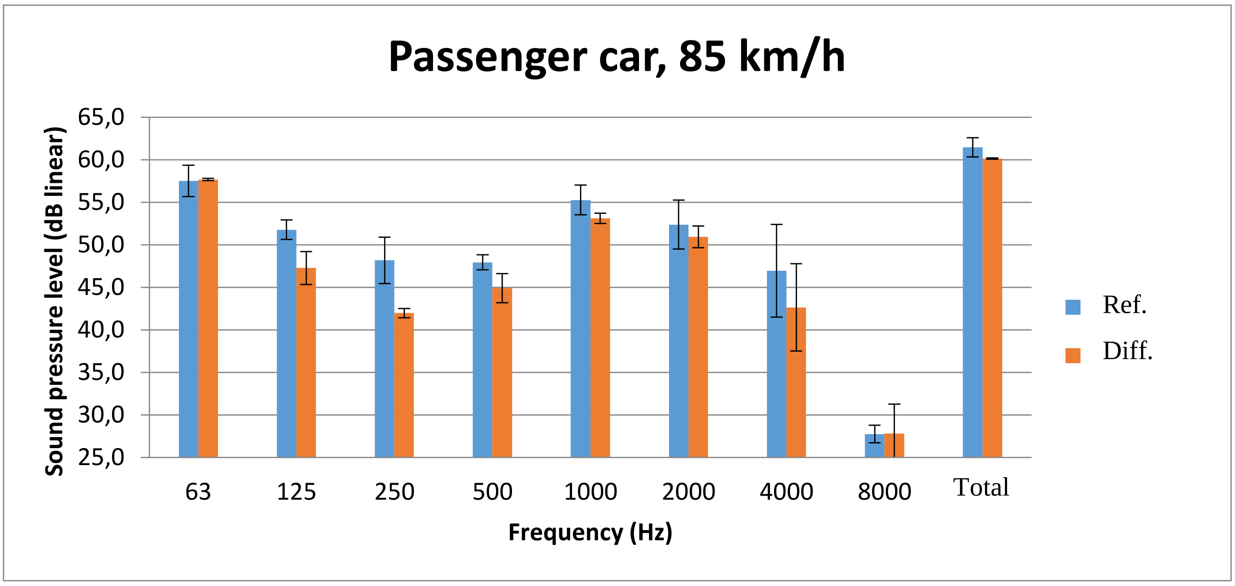

Fig. 13 Octave band spectra measured 50 m away from the road, on the reference location and at the diffractor.

What could be the cause of the decrease in noise reduction at 50 m? The author can think of four possible causes, which may act in combination:

- it is a well-known phenomenon in all noise propagation measures (including conventional screens) that noise reduction decreases with increasing distance. This is because sound waves propagate along curved lines rather than straight lines, owing to inhomogeneities (wind speed, temperature gradient) in the atmosphere. Sound waves initially bent upwards tend to bend down to the Earth's surface after a certain distance. This effect logically occurs with diffractors as well;
- there may also be an effect due to a poorer signal-to-noise ratio: when walking away from a road on which vehicles are travelling, the perceived level of noise from those vehicles decreases by geometric expansion[‡]. As a result, the noise level at 50 m will, in theory, be about 12 dB lower than the noise level perceived at 12 m. Close to the road, the noise from the passing test vehicle will be so high that background noise will not affect the result of the measurement. At 50 m, some contribution of background noise (mainly from other cars) may be perceivable. To give an idea: the effect of a background noise level of 45 dB on noise reduction measured 50 m behind the diffractor may be 0.3 dB. With a background noise level of 50 dB the effect may be as great as 0.8 dB;
- although the reference location was chosen carefully, the propagation path may still be slightly different from that to the measurement points behind the diffractor. Ground reflections are a complex and frequency-dependent phenomenon and may influence the result to some extent. Evidence to a part being played by ground absorption/reflection is provided among other things by the difference of 14.8 dB between the measurements at 12 and 50 m for the passenger car on the reference location, whereas the difference to be expected on account of geometric expansion would be 12.3 dB. This does not mean that the uncertainty of measurement is 2.4 dB: the propagation path is "similar" (pastures on both locations), but this effect still contributes to the uncertainty of the measurement result – roughly by 0.5 to 1 dB.
- The presence of a house on the other side of the road off the reference location could slightly increase the noise level, by reflection. However, it can be easily demonstrated that the influence is not greater than a few tenths of a dB: if instead of the house front there was an infinitely high, infinitely long and perfectly reflecting wall, the influence would still be as small as 0.6 dB.

[‡] Noise emitted by a point source such as a vehicle propagates in concentric hemispheric wave fronts. As the wave front moves further away from the source, the sound energy is distributed over an ever expanding hemisphere, which results in a decreasing sound pressure level. It can be demonstrated that sound pressure level drops by 6 dB per doubling of distance.

5. Conclusions

Although the method used for the Controlled Pass-By measurements is not standardized, the results may be expected to give a good indication of noise reduction by a diffractor on a low screen as configured and installed at Losser; of course, this applies only to the height of measurement chosen, i.e., 1.2 m above the road surface§.

At the distances of 12 and 30 m high to very high noise reductions – up to 9 dB – were observed, especially for the passenger car travelling on the lane closest the diffractor. The reduction is a bit lower when this car is driven on the other lane of the road, but still substantial: 6 to 8 dB. At the same distances, the reduction of noise from the lorry is – as could be expected – a bit lower: 5 to 6 dB, both when travelling on the diffractor's side and on the other side of the road.

It should be observed that a markedly lower noise reduction was recorded at the 50-m measurement point: about 4 dB for the passenger car or the lorry driven on the lane alongside the diffractor, and 2 to 4 dB when travelling on the other side of the road. It is not obvious why a 4-dB reduction was measured on 11th April and only a 2-dB reduction on 3rd May, but the most probable explanation is different weather conditions.

These results show that diffractors can improve the comfort of people living in the vicinity (within 50 m of may be more) of busy roads producing a lot of traffic noise. As the diffractors only bend the sound waves upwards, they are beneficial for people in the ground or first level of one family dwellings or for people relaxing in their garden. In Belgium e.g. it has been a tradition for many decades to build one family dwellings along busy secondary roads, leading to the adverse situation that many people are exposed to high traffic noise levels. Hence there are a lot of situations for which diffractors could be very useful.

It is worth noting that the noise reduction at 50 m – i.e., about 4 dB for traffic on the lane next to the diffractor – is still significant and substantial. It is comparable with the effect of a well-performing fairly recent low-noise pavement (LNP). The noise reduction provided by an LNP tends to decrease with time (typically at the rate of 0.7 dB/year!). In this context, a 4-dB noise reduction with a test setup only about 50 cm high and about 1 m wide can be considered a remarkable achievement. For vehicles travelling on the other lane, the reduction ranges between 2 and 4 dB. Normally speaking, noise reduction will remain the same over time as long as the slits are not becoming seriously clogged, but this may, of course, be remedied by cleaning them.

Acknowledgements

The participation of Kristof De Clerck and Lenert Verheyen of AWV in carrying out the noise measurements and driving the lorry is much appreciated and AWV itself is thanked for making the team and lorry available. Colleague Philippe Debroux of BRRC is thanked for carrying out the measurements. The cooperation of Bert Jan Danker of 4SILENCE in the practical organization of the tests (asking permissions to roadside residents and the road manager) and in making measurement reports and plans available is also highly appreciated.

6. References

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§ The most important limitation of the method used is that non-standardized "vehicle-noise spectra" were used in testing the noise-abating qualities of the diffractor. In other words, different results may be obtained with other test vehicles. Yet, as stated, the method may be expected to give a "good indication" of the effectiveness of the test setup at Losser.