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NOISE CONTROL FOR A BETTER ENVIRONMENT

The barrier effect of roadside diffracting elements for standard noise calculations

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ABSTRACT

By using elements with quarter-wavelength resonators of different depths alongside a road, noise can be diffracted upwards to create a zone of noise reduction behind these elements. Measurements at a short distance, up to 15 meters, have proven that a noise reduction up to 4 dB(A) can be achieved. The noise reduction at long distance, up to 600 meters, was calculated numerically by combining a finite element model (FEM) and a parabolic equation model (PE), taking a downwind condition into account. These results are used to design an engineering approach that represents a barrier effect. This approach can be implemented in the standard noise calculation models, such as the Dutch national model or the ISO 9613-2 standard. The steps that are used for this engineering approach are explained. This involves the measurement of the intrinsic characteristics of the diffracting elements and empirical relations that use these characteristics.

Keywords: Traffic noise, Diffracting elements, Standard noise calculation
I-INCE Classification of Subject Number: 31

1. INTRODUCTION

Traffic noise is major contributor to annoyance, so the application of both conventional and new mitigating measures is considered constantly. A non-conventional measure consists of a series of quarter-wavelength resonators located alongside a road, see Figure 1. The concrete element shown in the figure is called a diffractor or WhisStone[1,2]. Due to the resonances the grazing sound is diffracted upwards and a shadow zone results. In this way a barrier effect is created with a minimum disturbance of the view.

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In standard noise calculation models, such as ISO 9613-2 or the national Dutch model SRM2, an engineering approach is defined to determine a barrier effect. The barrier effect of the diffractor differs from the standard barrier effect. For example, the cavity depths of the diffractor shown in Figure 1 vary between 60 and 150 mm, which results in a main diffractor effect between 500 and 1500 Hz. So an engineering approach for the diffractor has been developed.

Figure 1. Diffracting elements alongside a road (1 meter wide).

The diffractor effect has been measured at relatively short distances, up to typically 15 meters. To determine the noise reduction at longer distances numerical calculations have been used to exclude uncertainties due to ground absorption and meteorological effects. Figure 2 shows the method that has been used[3]. It combines a finite element model (FEM), that includes the geometry of the diffractor, and a Green's function parabolic equation (GFPE), that includes a downwind condition and a 600 meter range.

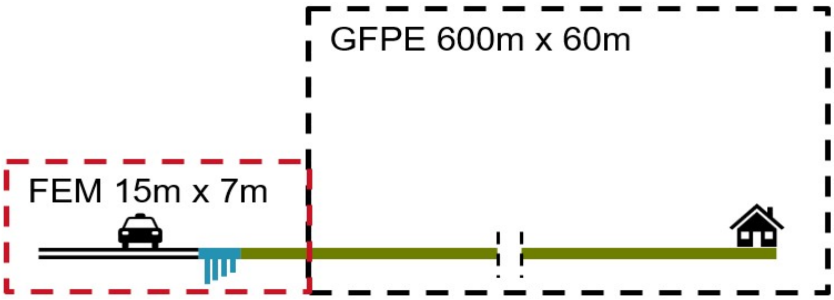

Figure 2. Combination of the finite elements model (FEM) and the Greens function parabolic equation (GFPE) to calculate the diffractor effect at long range.

The steps and results for an engineering approach are described in this paper. Section 2 contains two steps that are needed as input for designing the engineering approach. 1) A measurement set-up to determine the acoustic characteristics of the diffractor in octave bands, and 2) Numerical results of the diffractor effect at long range using different settings, such as traffic lane distance and the amount of absorption for the road and the ground. Section 3 describes the engineering approach based on the numerical results and the acoustic characteristics. The conclusions are given in Section 4.

2. ROADSIDE DIFFRACTING ELEMENT

2.1 Measuring acoustic characteristics

Following ISO 1793-4 "Intrinsic characteristics – In situ values of sound diffraction" for diffracting and/or absorbing elements on top of a barrier, a measurement method for the roadside diffracting elements is described in this section.

A diffractor can be designed to operate for certain frequencies or a frequency range, so the intrinsic acoustic characteristics are defined in third octave and octave bands. The octave bands are used in the standard noise calculation model.

Figure 3 shows the set-up for the measurements. A loudspeaker is located at 1.7 m from the diffractor at an angle of 0 and 45 degrees towards a microphone. The microphone is placed at 1.2 m height at 7.5 m from the loudspeaker (at 0 degrees). Two types of measurements are done: with the diffractor covered and uncovered. The ground is covered to create a reproducible and comparable situation. Figure 4 gives an impression of the measurements with the diffractor covered and with the loudspeaker at an angle of 45 degrees.

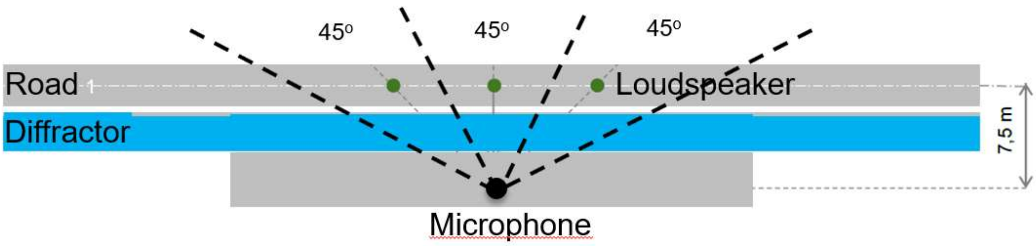

Figure 3. Set-up for measurements, with and without the diffractor covered, to determine the acoustic characteristics (measurements at 0 and 45 degrees).

Figure 4. Measurements with a loudspeaker on the road, a close-by reference microphone, and microphones at 7.5 m distance from the road. The diffracting elements and the ground are covered to serve as a reference.

The differences between the covered and uncovered measurements, in one-third octave and octave bands, are the acoustic characteristics of the diffractor (denoted as A_{diffr}). Table 1 shows results for a 1 and 2 meter wide diffractor. The latter one is a double row of the single row diffractor, so the frequency range is equal. The results show that the diffractor operates between 630 and 2000 Hz, with an enhanced effect for the double row diffractor. A maximum attenuation of 7.4 dB has been measured in the 800 Hz one-third octave band and 5.8 dB in the 1000 Hz octave band.

An increase of sound can be seen around 250 Hz. This increase is due to a surface wave that can travel relatively easy over the diffractor; the surface wave “hugs” the surface. This can happen when roughness features are small compared to the incident wavelengths.

Table 1. Acoustic characteristics of road side diffracting elements. For a single and double row diffractor, respectively 1 and 2 meters wide.

Single diffractor															
Frequency	100	**125**	160	200	**250**	315	400	**500**	630	800	**1000**	1250	1600	**2000**	2500
A_{diffr}(1/1 oct)		**-0,3**			**-0,8**			**0**			**4,5**			**1,6**	
A_{diffr}(1/3 oct)	0,1	-0,6	-0,4	-0,8	-0,9	-0,7	-0,7	-0,2	1,1	4,5	4,8	4,2	2,2	1,9	0,8
Double diffractor															
Frequency	100	**125**	160	200	**250**	315	400	**500**	630	800	**1000**	1250	1600	**2000**	2500
A_{diffr}(1/1 oct)		**0**			**-1,8**			**0,4**			**5,8**			**1,3**	
A_{diffr}(1/3 oct)	0,8	0	-0,8	-1,7	-2,1	-1,7	-1,6	0	5,7	7,4	6,4	4,3	2	1,7	0,4

2.2 Results calculated at longer distances

The simulations with FEM up to 15 m distance have been compared to measurement results[3]. A good resemblance was found both for the stationary measurements with a loudspeaker and pass-by measurements with light and heavy vehicles. In the 500 and 630 Hz bands an empirical correction was made, to account for a reduced resonance due to drainage.

The FEM results are combined with a GFPE model to determine the diffractor effect up to 600 meter distance and 60 meter height. Figure 5 shows the numerical GFPE results for the diffractor effect up to 600 meters distance and 60 meters height.

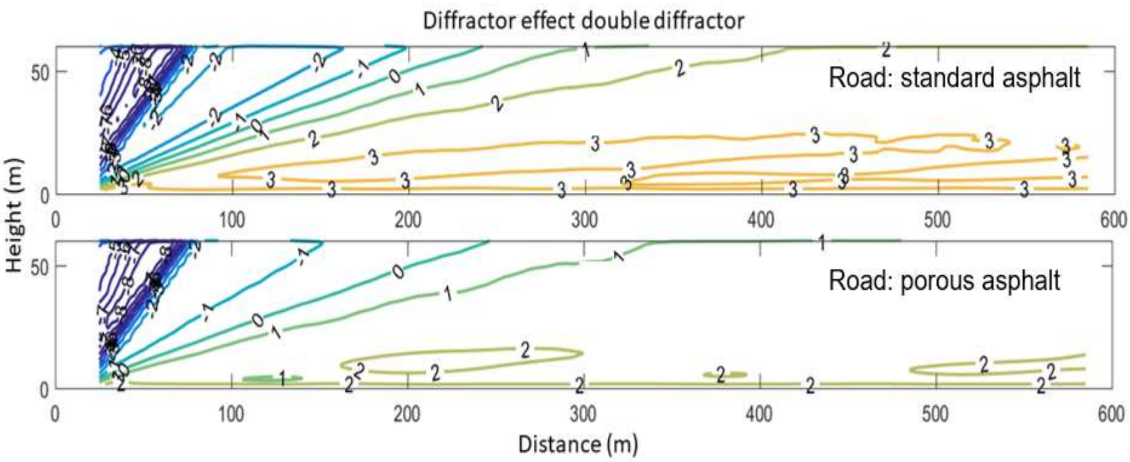

Figure 5. Numerical results for the diffractor effect in dB(A) up to 600 m distance. Positive numbers indicate a reduction of the sound level when applying a double row of diffracting elements (2 m wide).

The upper figure has a non porous road surface, a double row diffractor, and a hard ground surface beyond the diffractor. The diffractor effect is shown in dB(A) using a traffic noise source spectrum. The lower figure has a porous asphalt road, which reduces the effect of the diffractor. Simulations were performed for different environmental and geometrical settings, such as the distance between the diffractor and the road, and the absorption of the ground and the road. In this way it is possible to design a general barrier effect for all settings.

3. BARRIER EFFECT IN STANDARD NOISE CALCULATIONS

3.1 Engineering approach

In a first attempt for an engineering approach, the diffractor effect was fitted to a Maekawa based barrier effect (as used in ISO 9613 and the national Dutch model SRM2). The barrier effect uses the fresnel number N_f that accounts for the path length difference related to the frequency. However, by comparing different numerical results and by using different settings for a 'substitute barrier', no consistent relation could be determined.

Next, the diffractor effect was based on a more empirical relation, using numerical results. The approach includes:

1) the use of a substitute barrier of 0 meter high at the centre of the diffractor,
2) measured acoustic characteristics in octave bands $A_{diffr}(f)$ at a defined source-diffractor distance,
3) empirical relations for different source-diffractor distances using numerical results,
4) the definition of a shadow zone, based on a check for the fresnel number, the substitute barrier and a comparison with numerical results.

In Figure 6 the diffractor and the source-diffractor distance R is shown. The red solid line indicates the location of the substitute barrier.

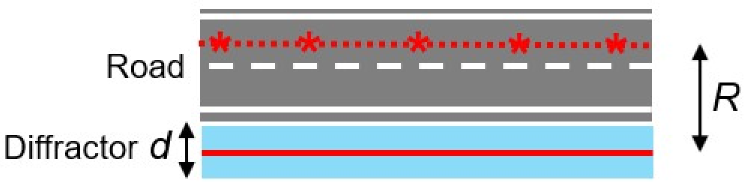

Figure 6. Schematic view of a diffractor (width d) next to a road. The solid red line indicates the position of the "substitute barrier" (with distance R to a traffic lane).

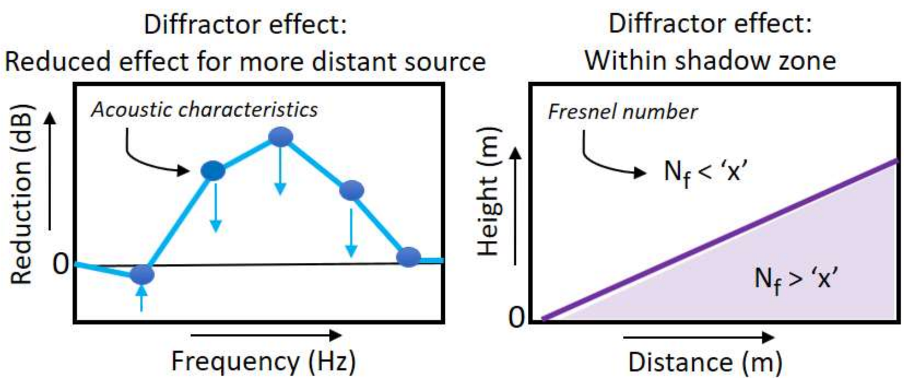

Figure 7. Schematic representation of the diffractor effect.
Left: the diffractor effect as a function of the frequency, where the arrows indicate a change in effect when the distance from the source to the diffractor (R) increases.
Right: the diffractor effect as a function of distance and height. Only within the shadow zone below the purple line there is a diffractor effect.

In Figure 7 the engineering approach is shown schematically. In the figure on the left, the diffractor effect as a function of the frequency is shown, using the measured acoustic characteristics indicated with the markers. The arrows indicate a reduced spectral effect for an increasing distance *R* from the source. In the right-hand figure the shadow zone is indicated below the purple line. The value for the fresnel number was chosen at -0.1, so for a small negative path length difference and higher values there is a diffractor effect.

As an example the diffractor effect as a function of the distance from the source to the diffractor *R* is shown in Figure 8, for the 1000 and 250 Hz octave bands (at longer distances, within the shadow zone). The diffractor is 2 m wide and the acoustic characteristics are determined at 1.7 m from the diffractor. A substitute barrier is used in the middle of the diffractor, so the acoustic characteristics A_{diffr} are shown at 2.7 m from the source with a marker. A linear relation was found between distance *R* and the diffractor effect in octave bands, with a negative slope for a positive effect and vice versa. The same linear relations for were found for the singe row diffractor and the other octave bands (and third octave bands).

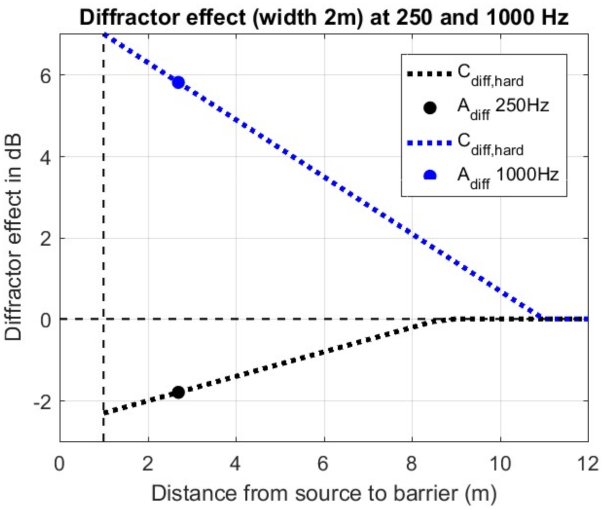

Figure 8. Diffractor effect as a function of A_{diffr} and distance R from the source to the diffractor for the 250 and 1000 Hz octave bands, at longer distances.

These relations were found for a diffractor situated next to a standard (non porous) road and an acoustically hard ground. Note that this is the same situation for which the acoustic characteristics are measured. To summarize, the diffractor effect $C_{\text{diff,hard}}$ is a linear function of *R* and $A_{\text{diffr}}(f)$ within the shadow zone:

$$C_{\text{diff,hard}} = \text{function}(R, A_{\text{diffr}}(f)) \quad \text{in dB} \tag{1}$$

$$C_{\text{diff,hard}} = 0 \quad \text{when } N_{\text{f}} < -0{,}1 \tag{2}$$

In the next section the effect of an absorbing ground is accounted for.

3.2 Effect of absorbing ground

Additional numerical results were used to expand the engineering approach for a soft ground near a diffractor that is located next to a road and is on the same level. In Figure 9 there are 6 configurations shown with an increasing area of soft ground towards the diffractor. The soft ground is modelled as grass (with a flow resistivity of 200 kPa·s/m^2) and is located at the receiver side.

In standard noise models a ground factor B is used, with B=0 for a hard ground and B=1 for a soft ground. The averaged ground factor, up to a distance of 10 m from the diffractor, is also shown in Figure 9.

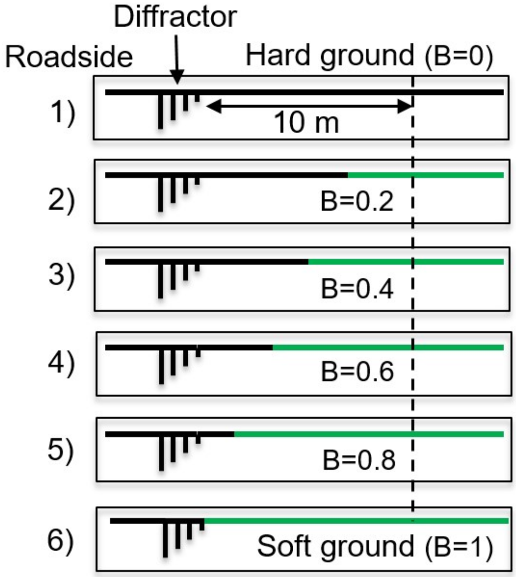

Figure 9. Six configurations with an increasing amount of absorbing ground near the diffractor (and an increasing ground factor B).

To illustrate the effect of an absorbing ground the diffractor effect without and with absorbing ground is shown in Figure 10. The results are shown in dB(A), for brevity, as a function of the distance from the source to the diffractor. For a hard ground the black broken line is the engineering approach, which uses the measured acoustic characteristic shown with the black marker.

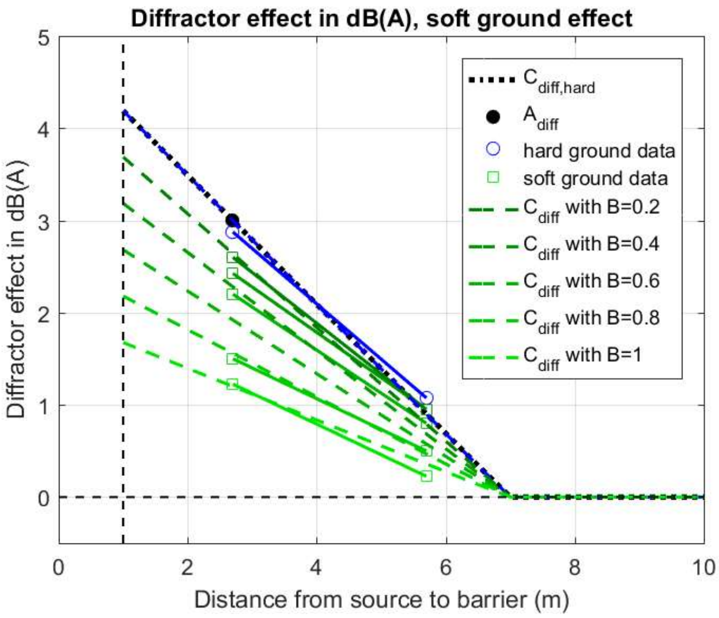

Figure 10. Diffractor effect in dB(A) as a function of distance from the source to the diffractor, including the effect of an increasing amount of absorbing ground near the diffractor (ground factor B ranging from 0 to 1). Comparison to numerical results shown with markers.

This approach is based on the numerical results at two distances from the source, shown with the blue markers (with a solid line between the markers). This is configuration 1) from Figure 9. The numerical results are based on the diffractor effect up to 500 meters distance from the source.

The numerical results for a soft ground are shown with the green markers, with a lighter green for a softer averaged ground. These results indicate a reduced effect for an increasing amount of soft ground near the diffractor. This reduction is compared to the situation with a hard ground and can be estimated with a linear factor as shown in equation (3):

$$C_{\text{diff}} = C_{\text{diff,hard}}(1 - b\,B) \quad \text{in dB} \tag{3}$$

With C_{diff} the diffractor effect, b a constant, and B the averaged ground factor up to 10 m distance from the diffractor.

In Figure 10 the results for equation (3) are shown with the green broken lines. A good comparison with the numerical results can be seen. This engineering approach has also been used for the octave band results. Combining equations (1), (2) and (3) completes the engineering approach for the diffractor.

The approach is being implemented and tested is the national Dutch model, for a basic geometry as well as for more complex geometries.

4. CONCLUSIONS

A roadside diffracting element causes noise to be diffracted upwards resulting in a zone of noise reduction behind these elements. At nearby distances the diffractor effect can be measured accurately, at larger distance numerical simulations need to be used. For the use of standard noise calculation models, such as the Dutch national model or the ISO 9613-2 standard, an engineering approach was developed and has been presented in this paper. It is based on numerical results as well as the in-situ measured acoustic characteristics.

When using standard calculations, the diffracting elements can be modelled as a barrier, but the engineering approach differs from a standard barrier effect. Instead empirical relations were developed. At present the engineering approach is being tested in more complex situations, for instance in the combination with other barriers between the source and the receiver.

5. REFERENCES

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