Dealing with Anomalous Diffraction Behaviour in Noise Standards Using Sound Particle Diffraction

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Introduction

Standards for calculating environmental noise must incorporate diffraction in some way; a completely black sound shadow behind buildings leads to unacceptable deviations from reality. Here a compromise must be found since the wave-based methods that incorporate diffraction most accurately place heavy demands on computer resources and are impractical for the great majority of noise control situations. The current standard recipe uses so-called "detour" methods, which have been used in ISO 9613-2 [1] for many years and will form the basis of diffraction estimates in the CNOSSOS-EU standard. Detour methods are a rough approximation and can, in very simple cases, be calculated without a computer. However, this simplicity comes at a price in the form of unphysical effects in predicted sound fields, and deviations from more sophisticated methods that can exceed 10 dB in unremarkable situations.

The Nord2000 standard [2] uses more refined wave-based diffraction procedures and can serve as a good benchmark for other diffraction methods. However, this standard can return anomalies if used without care because it is limited to two diffraction events.

In this paper, we show that estimates of diffraction effects can be significantly improved in a range of situations, without having to resort to expensive wave-based methods by using a sound particle simulation in combination with so-called "uncertainty-based" diffraction protocols. Unphysical discontinuities in sound fields are removed and the results lie closer to wave-based methods than detour methods. Since we remain in the framework of geometrical acoustics, the method can be used on larger scales than wave-based methods, due to reduced computer resource requirements. The method enjoys a further advantage over the standards as it is a fully 3D method whereas the others are considered as "two-and-a-half" dimensional.

Diffraction with Detour Methods

The ideas behind detour methods were explored most famously in the 1960s by Maekawa [3] and have been used as a standard procedure to estimate diffraction phenomena in noise control for many decades [1,4]. Heuristically, the model can be thought of as stretching a ribbon or rubber band between a source and a receiver. If an obstacle is encountered (or indeed obstacles), the rubber band is stretched to go tightly around the edge of the obstacle(s). Three paths are typically used: one that goes around to the left, one that goes around to the right and one that goes over the top. The path length difference between these paths and the direct route from the source to the receiver is then calculated and a simple empirical formula is used to obtain a value for the screening effect. It is important to note that different input constants are used depending on whether the rubber band is bent round a single edge or multiple edges.

Diffraction with Sound Particles

Modelling acoustics with sound particles (effectively ray tracing) has also been around for decades and is well suited to reverberant situations. However, incorporating diffraction into such geometric models is a long-standing problem since wave effects are not present and detour methods are unsuitable since they only consider paths that connect immediately with a receiver.

Since the mid-1980s, Stephenson and co-workers have developed the idea of so-called uncertainty-based diffraction in which particles are deflected through "virtual walls" that extend from diffraction edges [5]. The angle of deflection is determined by first calculating by-pass distances from diffracting edges and using these to obtain an effective aperture width "*b*". This in turn is fed into a simple formula derived from Fraunhofer diffraction

$$\theta = \frac{\tan(2\sqrt{2}bR)}{2\sqrt{2}bR} \tag{1}$$

where "*R*" is a uniform random deviate, to determine a suitable angle for the particle to turn through. The method is sometimes known as Sound Particle Diffraction (SPD) and further details may be found in the references [4-6].

A Simple Double-Screened Situation

We begin by showing a simple situation where sound particle diffraction can offer more sensible results than the detour methods. A schematic diagram of the situation is shown in Figure 1. All the receivers are either singly or doubly screened from the source and the only significant contribution comes from diffracted sound. The walls are considered fully absorbing for academic purposes.

The sound intensity levels are calculated with and without the walls and the results subtracted to obtain the screening effect. We plot results for the sound particle diffraction method, the ISO 9613-2 and the Nord2000 method in Figure 2. For the purposes of academic comparison, we remove limits on diffraction from the ISO implementation. The situation mimics an outdoor "free-field" since the bounding box is set to fully absorbing. This allows us to test diffraction effects in isolation. We use a 500 Hz source with 100 dB sound power for all the results in this paper.

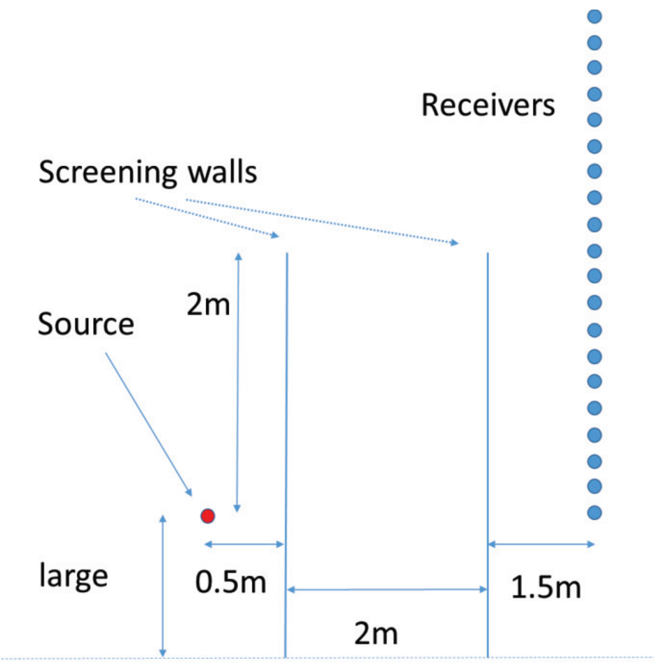

Figure 1: Schematic diagram (not to scale) of a double-screened situation. The source operates at 500 Hz, 100 dB sound power. The receivers are 0.2 m apart and start on the same level as the source. The situation is set up so that contributions from reflections and atmospheric effects are negligible.

The results show large discrepancies between the detour method used in the ISO 9613-2 and the more physical wave-based method used in the Nord2000. In additional to level differences well in excess of 10 dB in the deep shadow zone, the detour method shows a discontinuity as it passes from singly-screened to doubly-screened, which has been documented elsewhere [7] and reflects the fact that this simple method must handle single and multiple diffraction differently.

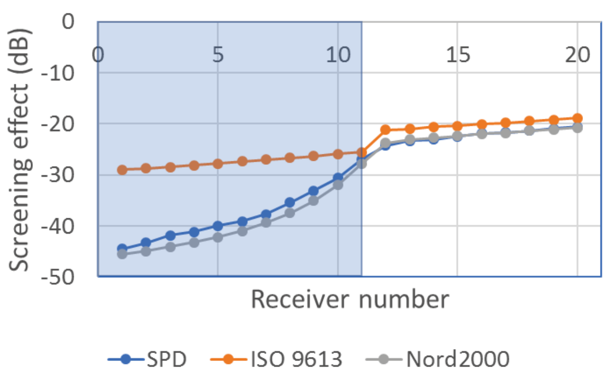

Figure 2: Screening effect from the double wall situation shown in Figure 1. The receiver number goes from 1 (the lowest receiver in Figure 1 in the deep shadow zone) to 20, the top receiver. Blue curve shows the sound particle results, orange curve shows the ISO 9613-2 results and the grey curve shows the Nord2000 results.

The SPD results are closer to the Nord2000 results. The slightly higher estimation of levels in the shadow zone is primarily a result of the approximations made to determine energy distribution following diffraction.

Diffraction Through an Offset Gap

We now consider a more complicated situation that is known to cause trouble for detour methods. It has two perfectly reflecting boxes offset horizontally from one another. One box comes into the frame from the bottom and the other in from the top. We assume the boxes are long and tall so that there is little contribution to the sound field from around the extremities. In addition, the geometry is arranged so that the only reflections come from the blocks. The results are shown in Figure 3, SPD results in panel (a), ISO results in panel (b).

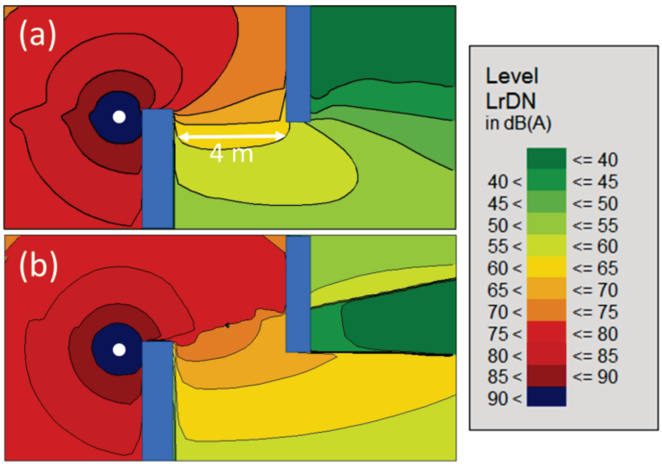

Figure 3: Sound level field map showing diffraction through a gap between two offset blocks. Panel (a) shows sound particle diffraction results, panel (b) shows results from ISO 9613-2. The source is indicated by white dots, 500 Hz, 100 dB sound power.

The results reveal a type of situation that the ISO standard is not designed to deal with. Although the method addresses paths between sources and receivers that go around several edges, to limit the calculation complexity, this path always takes a convex route around the obstacles – it has either exclusively right turns or exclusively left turns. This means it cannot deal with the zig-zag that goes through the middle of the two blocks in Figure 3, even though this is close to being a direct path. As a result, we see a dark green area in panel (b) where little signal arrives. The field is bounded by sharp discontinuities in the field marking the transition points between the diffraction protocols. The SPD method delivers a smoother sound field because particles are able to zig-zag and find the shorter route through the gap.

The fluctuations in the field seen in the top right of panel (a) are due to statistical uncertainties since relatively few particles arrive in these areas. Using longer calculation times can be used to smoothen the field – run times for the figures here were on the order of 10 minutes using a standard laptop computer.

Diffraction Around a Cylinder

We now consider diffraction around a perfectly reflecting cylinder, approximated with a circular arrangement of 12 polygons. Again, reflections come exclusively from the cylinder so the only route to the shadow zone is through diffraction. The results are shown in Figure 4, SPD results in panel (a), ISO results in panel (b).

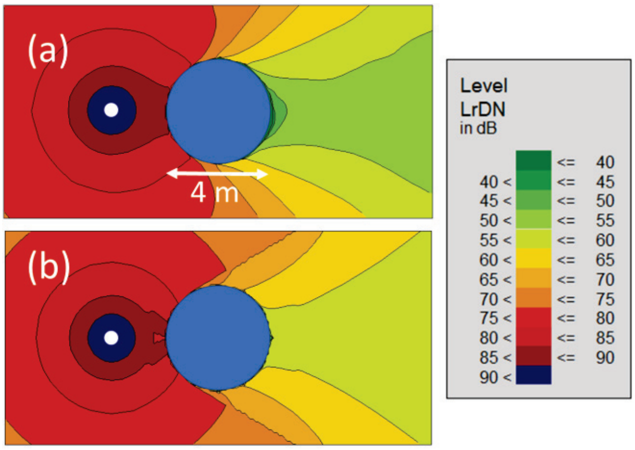

Figure 4: Sound level field map showing diffraction around a cylinder. Panel (a) shows sound particle diffraction results, panel (b) shows results from ISO 9613-2. The source is indicated by white dots, 500 Hz, 100 dB sound power.

In this case, because the diffraction paths are always convex, the ISO 9613-2 [panel (b)] delivers qualitatively better results than in the previous case with the blocks, albeit with some angular features. The levels are somewhat higher than the sound particle method as we also saw in the example in Figure 2. The notch in the field just to the left of the cylinder in the ISO results is due to a corner between two cylinder polygons. The SPD results do not show this because deflections of the sound particles due to diffraction effects on the source side of the cylinder increase mixing of the sound field.

Conclusions

We have seen that modelling diffraction using the detour methods prescribed by major environmental noise standards can lead to anomalous results. It is worth emphasising that detour methods are much better than assuming a completely black sound shadow and have proved useful for decades, especially in times when computer power was not as it is now. We have used examples here to highlight known difficult cases – in the course of normal use, problems of this nature are generally less acute. Nevertheless, computer capabilities are now at a point where it makes sense to reconsider the compromise in noise standards between acceptable calculation effort and accuracy of results, as well as the probability of running into trouble with the difficult scenarios we have seen. Diffraction using uncertainty-based methods and sound particle techniques offers a new recipe to support this.

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