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DIFFRACTION AROUND CORNERS AND OVER WIDE BARRIERS IN ROOM ACOUSTIC SIMULATIONS

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The diffraction effects of screens and other obstacles have been integrated in a room acoustic computer model using a theoretical model by Pierce, which is a further development of the original Geometrical Theory of Diffraction by Keller. This diffraction model is particularly interesting because it allows the modelling of a screen as a wedge with any opening angle, or as a wide barrier with two diffracting edges. Also the combination of two screens is possible. Another feature is that the model is valid even with the source or receiver located at the surface of the barrier. A major advantage of the method as implemented in the Odeon room acoustics software is the automatic detection and calculation of transmission paths around one or two edges. The basic assumptions, limitations, and examples of verification will be discussed.

1. Introduction

Algorithms for calculation of diffraction of sound around screens have been implemented in the Odeon room acoustics software according to the theory for single and double diffraction derived by Allan D. Pierce[1]. The method is more complicated to implement than the more common method by Maekawa[2] but it should generate better results in the deep shadow zone far away from the edge and close to the screen, and also in cases of thick barriers and other cases of double diffraction.

The algorithms are implemented for point sources, only, and cannot be calculated for surface or line sources. An important part of the new implementation was to make it user-friendly, i.e. to develop a method for automatic detection of the shortest path between source and receiver around one or two screens placed randomly between source and receiver.

In order to evaluate the results obtained with the implemented diffraction model, comparisons have been made with several cases of measured results found in the literature. The different tests were made in anechoic or semi-anechoic situations. When using the screen diffraction in a more reverberant room the contribution from the diffracted sound will be added to the reverberant field and will thereby add some extra energy in the calculation. However, in a reverberant room the diffracted energy will be very small, almost negligible compared to the reverberant energy and therefore the algorithms will only lead to improvements of the simulations in less reverberant rooms.

2. Theory

Pierce[1] considered the diffraction of a sound wave from a point source around a rigid wedge or a three-sided barrier. The solution is convenient for numerical predictions as it is derived in terms of auxiliary Fresnel functions and interpreted in terms of diffracted rays in accordance with Keller's geometrical theory of diffraction. This diffraction model is valid for a wide range of applications, e.g. the model allows source/receiver positions close to the side of the barrier. Ivey & Russell[2] have shown that Pierce's model is superior to several other diffraction models and it gives good agreement with experimental data for wide, building-size barriers.

3. Propagation paths of diffracted rays

The contribution due to diffraction is calculated if the source is not visible from the receiver point and a propagation path with single or double diffraction can be found, see Fig. 1 and 2. The contribution is calculated for the shortest path of diffraction around the screen(s). The edge, for which diffraction is calculated, is regarded as infinitely long and therefore no other edges than the one describing the shortest path, will contribute to the calculation. In other words; no more than one diffraction path is used for each pair of source and receiver. This simplification has been chosen because the calculations in Odeon do not take the phase into account, and the phase would be important if several diffracted contributions should be combined.

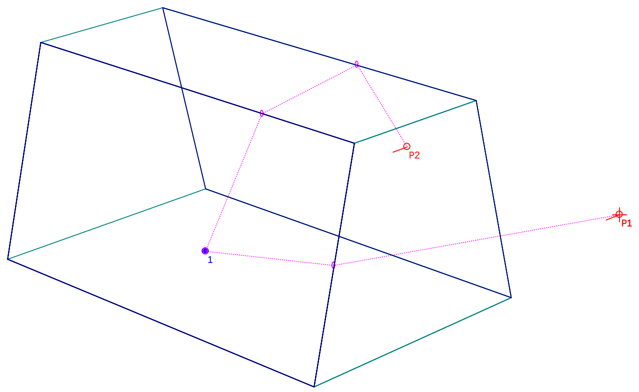

Figure 1. Example of automatically detected propagation paths around one or two edges (two sources and one receiver).

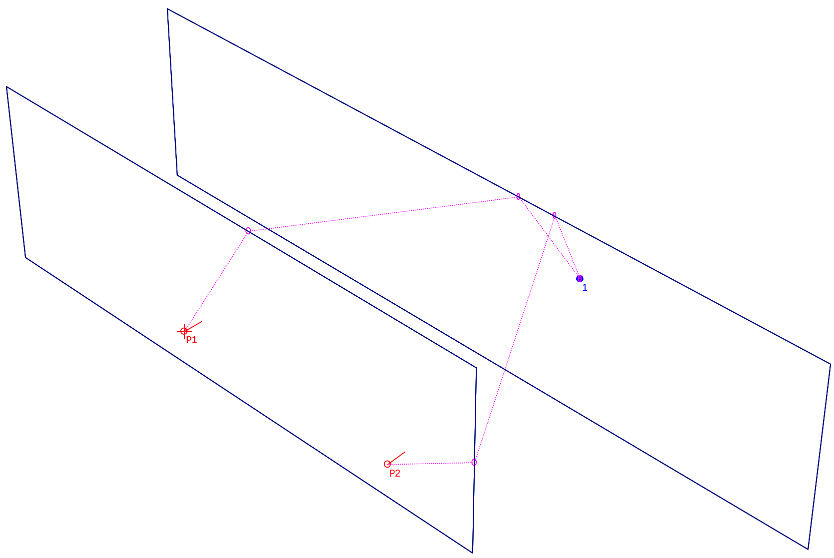

Figure 2. Example of automatically detected propagation paths around two thin screens (two sources and one receiver).

The detection of the diffraction path begins with finding the surface that is first met when travelling on a straight line from the source towards the receiver, and similarly, finding the surface first met when travelling in the opposite direction. Next the algorithm finds the edge closest to the direct line between source and receiver. The diffraction point at the edge is defined as the point from where the shortest line orthogonally from the direct line to the edge can be drawn. With two screens two diffraction points are found. If these two diffraction points can be connected without other surfaces blocking the path, a double diffraction path has been identified. An alternative diffraction point is found by considering a straight line from the source to the diffraction point closest to the receiver; if different, the shorter of the two diffraction paths is used.

In case of diffraction over two edges that are not parallel, an approximation is made by shifting the coordinate systems, because the theory assumes parallel edges.

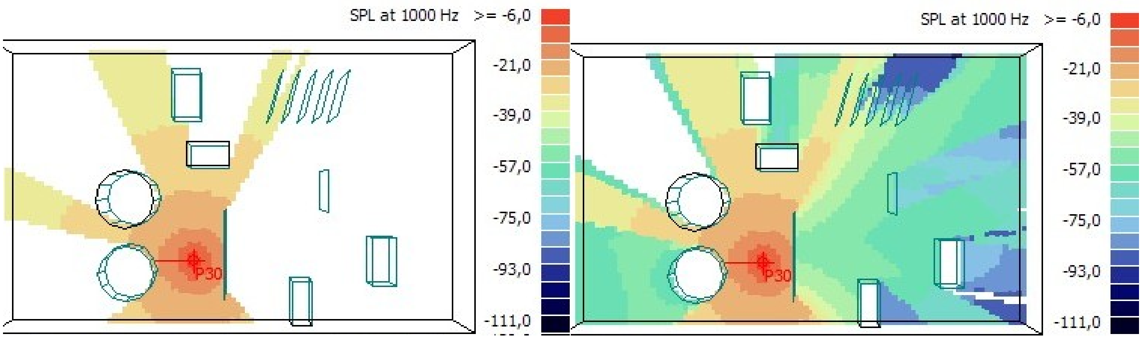

Figure 3. A grid of SPL at 1000 Hz in a test-setup with a single point source, without and with the edge diffraction turned on.

As seen on the plots of sound pressure levels in Fig. 3 the diffraction algorithm calculates energy in the shadow zones but it does not interfere with the calculated energy in the zones where direct sound is dominating. This is also because Odeon does not calculate the interference due to phase phenomena. It is also seen that a few areas remain uncovered, even with the diffraction algorithm turned on. These are areas where the sound has to travel over more than two edges, or cases where surface with the diffracting edge cannot be found from the direct line between source and receiver.

4. Verification against traffic noise barriers

In order to verify the diffraction model as implemented in Odeon, several cases of traffic noise barriers have been modeled and the results are compared to experimental data reported by Watts[3].

4.1 Traffic noise barriers with various shape

The relative insertion losses between a thin screen and different barrier types were measured in a 1/6th scale model setup using traffic noise spectrum[3]. The measurements were simulated in Odeon to test the new diffraction function. There are some uncertainties in the input-data, however. Absorption materials of the scale model are unknown and so the absorption properties of the surfaces in the Odeon simulation are estimated. The test set-up used in the measurements and in the simulations is shown in Fig. 4 and the different types of barriers tested are shown in Fig. 5.

In the measurements as well as in the simulations, a general road traffic noise spectrum was used to calculate the A-weighted sound pressure levels. The insertion losses were then calculated using the thin barrier as a reference. In the simulations two different reference barriers were tested in order to test possible differences in using a single surface or double surfaced barrier. The reference was represented by a single surface and a thin box of 0,01 m thickness, respectively. Table 1 gives the differences between the results simulated in Odeon and measured in the scale model.

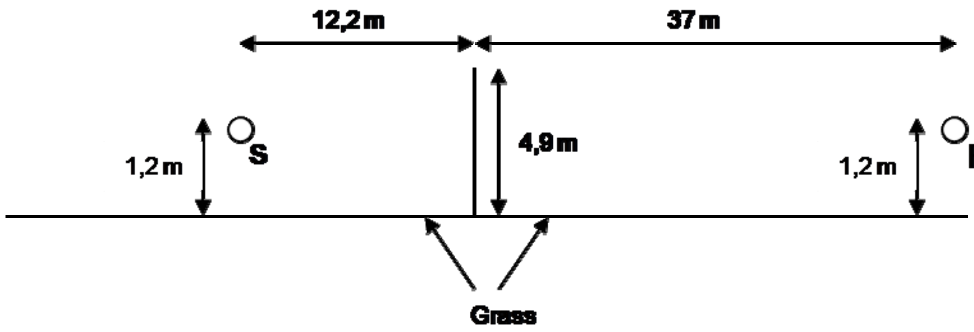

Figure 4. Measurement set-up. One source (S), one receiver (R), grass-land as ground condition.

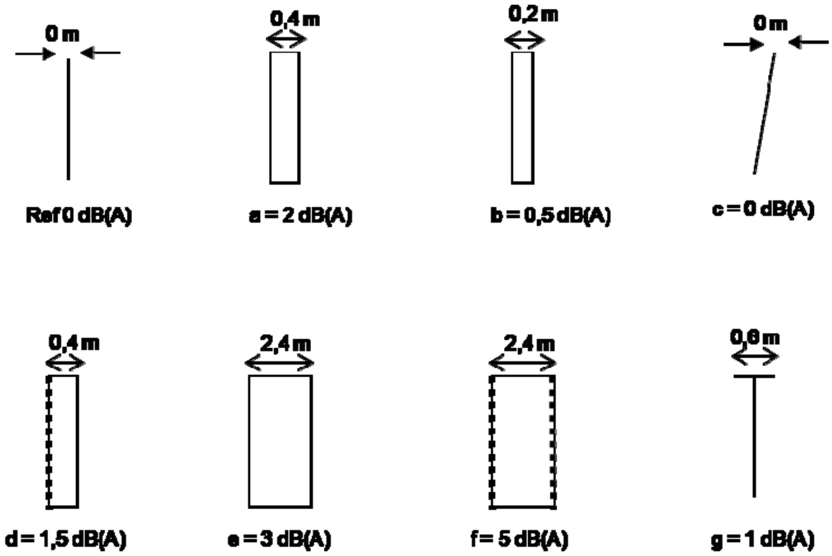

Figure 5. Measured insertion losses for different barrier types. The black spotted sides are sound absorptive material.

Table 1. Simulated results of attenuation of traffic noise compared with measured results

dB(A)	a	b	c	d	e	f	G
Calculated. Ref: Single surface	2,9	2,1	0,4	2,9	4,0	4,0	-
Calculated. Ref: 0,01 m thick box	2,9	2,1	0,4	2,9	4,0	4,0	-
Measured	2	0,5	0	1,5	3	5	1
Deviation	0,9	1,6	0,4	1,4	1	-1	-

Table 1 shows that all insertion losses calculated in Odeon deviate less than 2 dB from the measured results.

The diffraction algorithm in the calculations assumes that the test barrier is 100% reflective[1]. When comparing situation (a) with (d) or situation (e) with (f) the simulated results behave as according to this. Note that in the measurements situation (d) shows a lower insertion loss than for situation (a), even though situation (d) has more absorption added.

Another limit to the diffraction algorithm is shown in situation (g) where Odeon cannot produce a result of diffraction because the horizontal top of the barrier is not blocking the direct path between source and receiver, but it is blocking the diffraction path. Thus, no diffraction can be calculated for situation (g).

The comparisons of simulated results with the two reference barriers, shows very satisfying to be identical whether using a single surface or a thin barrier of 0,01 m. Also the overall tendency of a thick barrier giving a relatively larger insertion loss than a thin one shows that the simulated diffraction is going in the right direction. The fact that the insertion losses are relatively smaller in the measurements compared to the simulations and especially situation (b) with a relative thin barrier can indicate that the reference barrier in the measured test setup might not have been as thin as it is possible to make it in the simulations.

4.2 Verification of double screens

The relative insertion losses between a single thin barrier and two thin barriers were determined from traffic noise measurements in situ and documented by Watts[5]. The measurements were made as an average over two source position and six receiver positions. The same investigation was simulated in Odeon following the measurement setup as shown in Fig. 6 and the tested situations in Fig. 7.

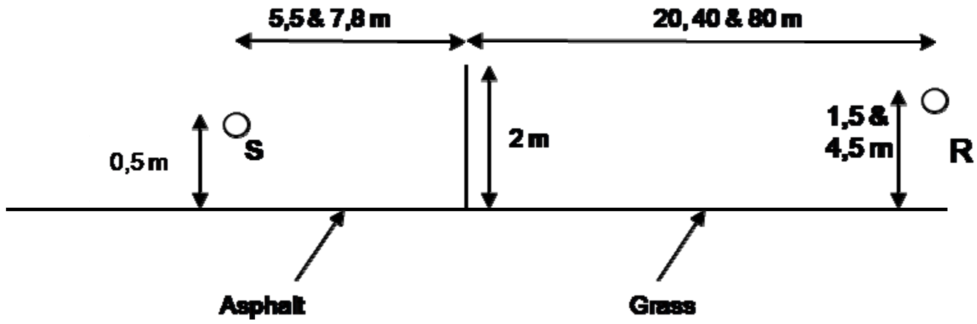

Figure 6. Measurement set-up. One source (S), one receiver (R), different ground conditions.

There are some approximations in the input-data. Absorption materials of the real situations are not known and the properties used in the Odeon simulated are therefore estimated. Other uncertainties lie in the unavoidable atmospheric conditions in in-situ measurements, and partly compensated for by a series of repeated measurements under different wind conditions[3].

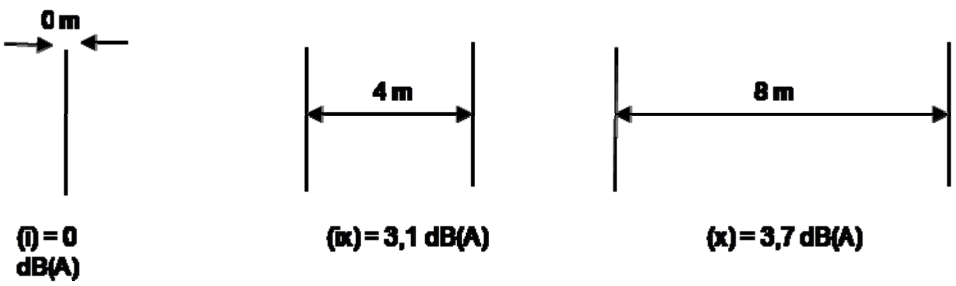

Figure 7. Measured relative insertion losses for different barrier arrangements.

Receivers where moved in each simulations, so they had the same distance to the closest screen in all three situations. Table 2 shows a very good agreement between measurements and simulations despite the sources of uncertainty.

Table 2. Relative insertion losses simulated and measured for the conditions shown in figure 7.

dB(A)	i	ix	x
Simulated	0	2,9	3,8
Measured	0	3,1	3,7
Deviation	0	-0,2	0,1

5. Verification in frequency bands

5.1 Scale model measurements with a thin half-plane

In 1977 Kawai et al[4] published measurements of diffraction around a thin half-plane in an anechoic room (5,86 m x 4,8 m x 4,5 m) to compare with calculations based on different theories of diffraction. The comparisons of measured and calculated results were presented as figures[4]. Some of these figures are pasted onto simulated result presented as grid responses from Odeon, so a direct comparison can be made as shown in Fig. 8 and 9.

Odeon is a high frequency model and it has its limits in small scale simulations as these ones as it does not calculate phase phenomena. In most cases the source is placed at or close to the plane of the screen. This will make the total energy larger partly due to mirrored energy and partly due to superimposed wave effects. In order to get a better correspondence between levels measured and simulated close to the source, the overall gain of the source in Odeon is adjusted with 3 dB when placed at the surface of the screen.

The measurement results were presented in 1/3 octave bands whereas the simulations are in 1/1 octave bands. Despite the differences in simulations and measurements, below figures give an idea of the strengths and weaknesses of the diffraction algorithms implemented.

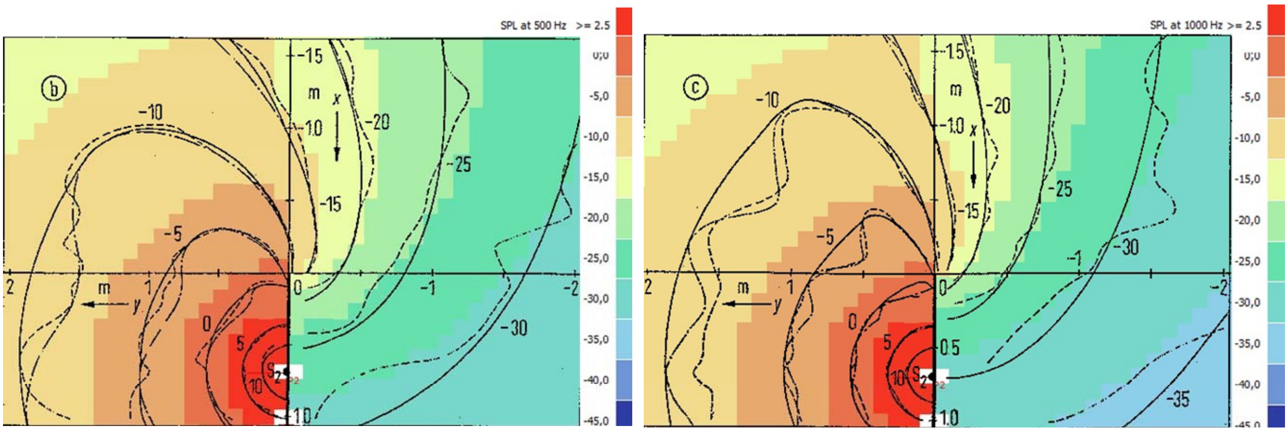

Figure 8. SPL at (b) 500Hz, (c) 1 kHz. The dashed lines are the measured results, the other lines are calculations based on different theories[4]. The coloured grid response is from the Odeon simulation.

In Fig. 8 is shown results with a sound source located on the side of the screen. Fig. 8 shows that there is a reasonable good agreement between the measured results from Kawai et al[2] and the Odeon simulations. In general the sound pressure levels in the shadow zone are a few dB higher in the simulations compared to the measured results.

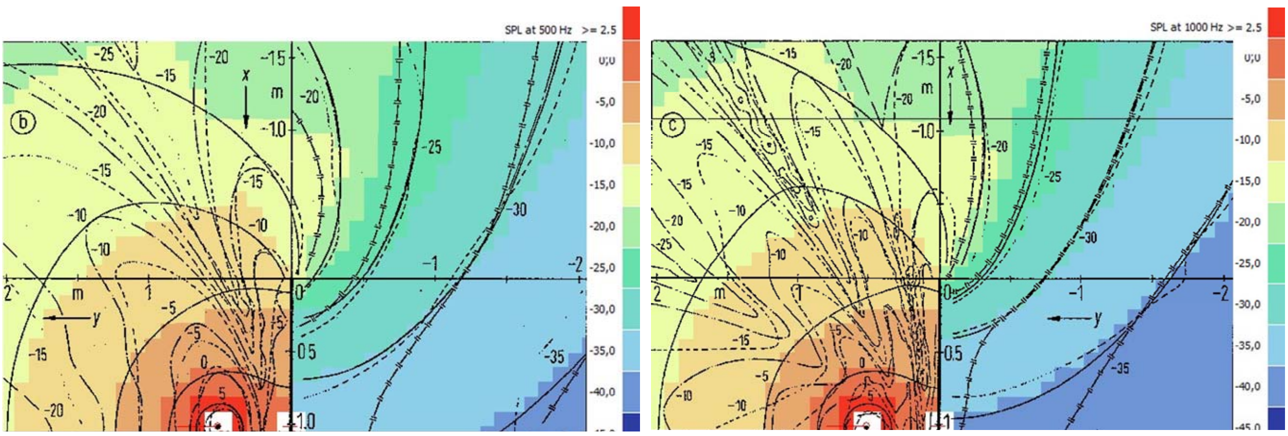

Figure 9. SPL at (b) 500Hz, (c) 1 kHz. The dashed lines are the measured results, the other are calculations based on different theories[4]. The coloured grid response is from the Odeon simulation.

In Fig. 9 is shown results with a sound source located at some distance from the screen. Fig. 9 shows that in the shadow zone there is a reasonable good agreement between the measured results and the Odeon simulations. On the source side the measurements show a complicated interference pattern, which is not reproduced by the simulations because the phase is not taken into account in the Odeon simulations.

Generally, it is found that the agreement with the measurement results in the shadow zone is very satisfactory.

5.2 Scale model measurements with many-sided barriers

In 1981 Kawai[5] published measurement results of diffraction around different barrier types in an anechoic room to compare with calculations based on different theories of diffraction. The comparisons of measured and calculated results were presented as figures[5]. Some of these figures are pasted onto simulated result presented as grid responses in Odeon, so a direct comparison can be made as shown in Fig. 10 and 11. The overall gain of the source in the Odeon simulations is adjusted according to the same rules as described above in section 5.1.

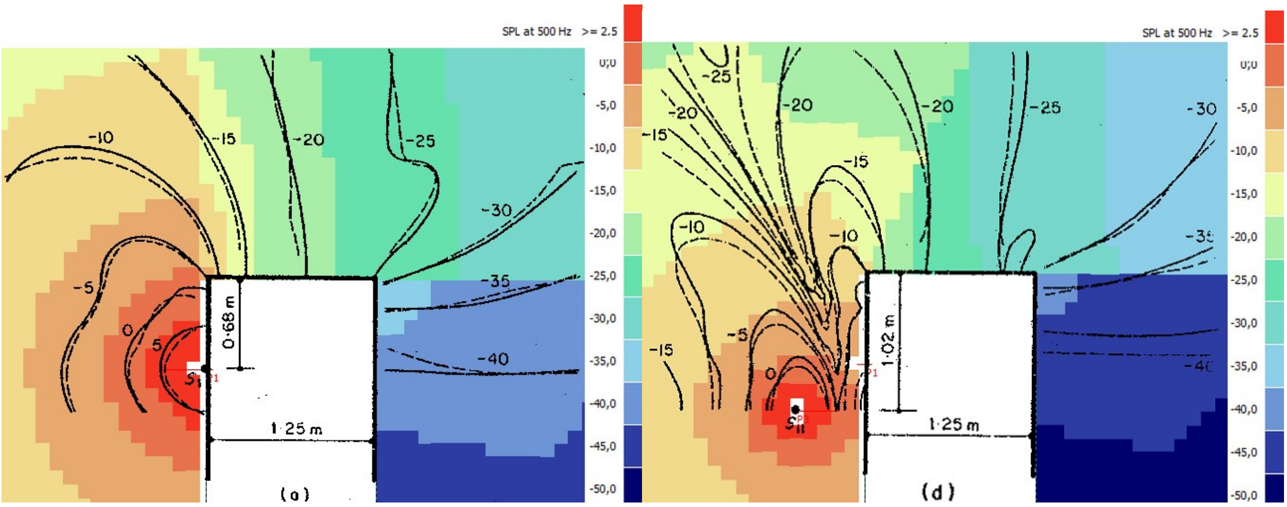

Figure 10. SPL at 500 Hz with two different source positions near a three-sided barrier. The dashed lines show measured results. The coloured grid response is from the Odeon simulation.

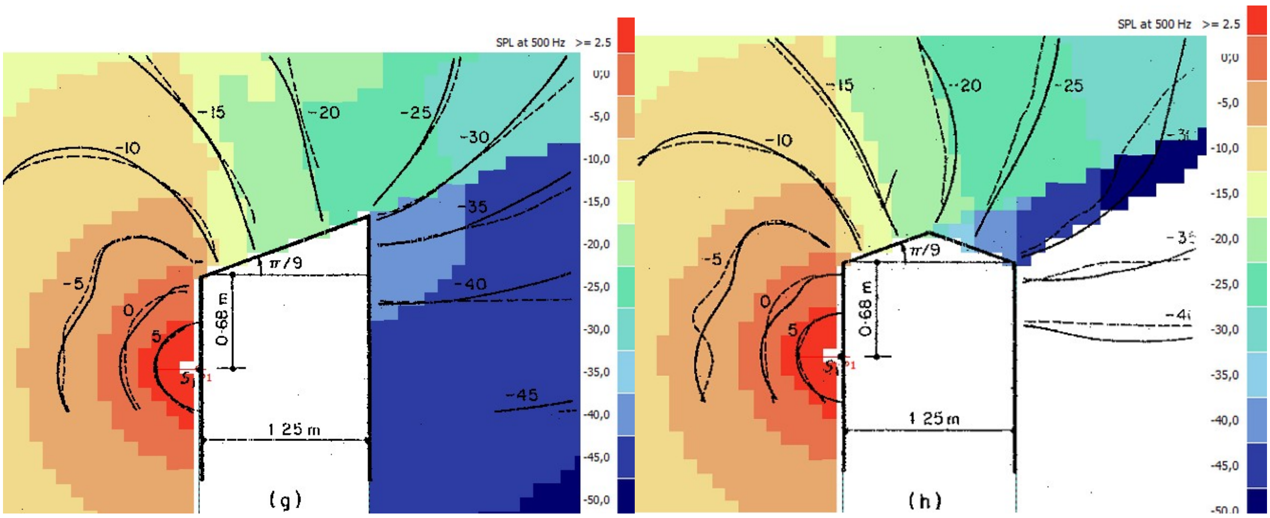

Figure 11. SPL at 500 Hz. The dashed lines show measured results. The coloured grid response is from the Odeon simulation.

Fig. 10 and 11 show that there is a very good agreement between measured and simulated results for diffraction around one edge than for diffraction around two edges. In the shadow zone behind the second edge the Odeon simulations show a slightly different shape of the diffracted sound pressure levels than the measurements. Fig. 11(g) shows that it is possible in Odeon to simulate double diffraction for edges with other angles than 90 degrees. Fig. 11(h) shows how the simulated results will stop before the third diffraction point; the threshold defining the shadow zone is a straight line from the source position through the third edge.

6. Discussion

When choosing the diffraction algorithms by Pierce for one and two edge diffraction it was with respect to these algorithms producing better results close to the barrier in the near shadow zone. The tests presented here have shown very good results for a single edge close to the screen and also good results far from the screen both for single and double diffraction, weather it is around a barrier or over two screens. Nevertheless the diffraction around a two-edged barrier in the near zone has shown to give a few dB too low SPL behind the second edge of diffraction.

The described implementation of a diffraction model is limited to the shadow zone behind objects. Diffraction effects also occur outside the shadow zone, causing interference with the direct sound and with reflected sound. Since Odeon simulations are based on sound energy calculations not taking the phase of reflections into account, the diffraction effects outside the shadow zone have not been included either. However, scattering effects caused by diffraction and leading to attenuation of reflections from small objects at low frequencies, the reflection-based scattering, is included.

7. Conclusion

In reverberant environments the diffraction effects are usually of very little importance. However, in environments with little or no reverberation the diffraction algorithm by Pierce has proven to be a significant improvement to room acoustic simulations. The results are limited to the shortest – and most important – diffraction path between a source and a receiver, even if more diffraction paths are possible. The diffracted sound is only calculated in the shadow zone, i.e. the contributions from diffraction in front of a barrier causing interference with the direct sound has not been included in the present implementation.

The calculation method has been verified by comparison with several cases of measured results, including single and double screens and wide barriers. In the latter cases it has been found that the diffraction around one edge yields results very close to the measurements, whereas diffraction around two edges yields results that can deviate a few dB from the measurements. All together the suggested diffraction method is a significant improvement of the room acoustic simulation software, meaning that the field of application has been extended.

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