Calculation of sound propagation with highly reflective environments

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ABSTRACT

Engineering models applied to calculate noise levels in residential areas caused by traffic sources are ray-based approximations of the real wave propagation. Difficulties arise if many reflective objects like buildings influence sound propagation and if reflections contribute significantly to the resulting levels. There are different techniques to deal with these problems and all of them have their pros and cons. Some of them are discussed with special attention for the precision and repeatability necessary if these calculation methods shall be applied to check the conformity of infrastructure projects with existing legal requirements. Noise prediction for low noise back-yards near roads with heavy traffic and methods to calculate the levels increase in street canyons are discussed. It is shown that the assumption of specular reflection in nearly all calculation methods is a good approximation even with diffuse reflecting facades, but nevertheless limits the finally possible accuracy of noise prediction.

Keywords: Sound, Propagation, Reflection   I-INCE Classification of Subjects Number(s): 76.1

1. INTRODUCTION

The prediction of noise and as an important part of it the calculation of sound propagation in agglomerations and other built-up areas is a challenge for all experts engaged in noise mapping activities. The knowledge about sound propagation over long distances taking into account the influence of the terrain and of meteorological conditions grew enormously the last decades, but completely different problems arise if the noise caused by a road, a railway line or any other sound emitting device shall be predicted nearby, but with many buildings and other screening and reflecting objects blocking the direct propagation path between source and receiver. In such cases it is by far more important to find and to take into account the propagation paths contributing most to the sound impact at the receiver position than to go deeper into the physical description of the propagating wave. In all engineering models with their simplification of the wave field swapping over such complex surfaces like built-up areas by geometrically well defined ray paths a lot of purely geometric problems arise that are often not overseen by acousticians developing new guidelines and standards dealing with noise prediction.

An attempt to improve this situation is the approach of “Quality assurance” of software for the calculation of sound outdoors according to the ISO 17534-series (1). The responsible working group develops measures to ensure a better precision in the sense that the spread of results obtained with different software packages applied on the same problem is minimized. Therefore for a lot of theses above mentioned and more or less geometric problems possible alternatives have to be investigated and finally all agreed solutions for a specific calculation method shall be published in a method specific Technical Report as part of the ISO 17534-series.

In the following some of these geometrical aspects are presented and discussed.

2. SEGMENTATION OF EXTENDED SOURCES

In noise mapping projects most of the traffic sources are taken into account as line sources, as long as timely averaged equivalent sound pressure levels caused by moving sound sources like cars or trains

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shall be determined. In the models to be processed by noise calculation programs such line sources are represented by a sequence of points geometrically defined by their coordinates and shown graphically as polygon lines. It is state of the art to subdivide this line source into elements so small that each of these elements can be replaced by a point-source at its center and with an emission depending on the length related sound power level of the line-source and the length of the element. A minimal requirement is to replace each line source segment – this is the straight line between two neighbored polygon points – by one point source. But even this segment may be too extended in the sense that subparts of it have different distances to the receiver and may contribute too differently to replace them by a single point source. Therefore different techniques can be applied to subdivide straight line source segments into smaller elements.

To check the accuracy of these different strategies to subdivide a line source, we apply the scenario shown in figure 1. There is a very large line source segment extended ± 1000 m at each side from two receivers in distances of 100 m and 25 m and in a height of 4 m above ground.

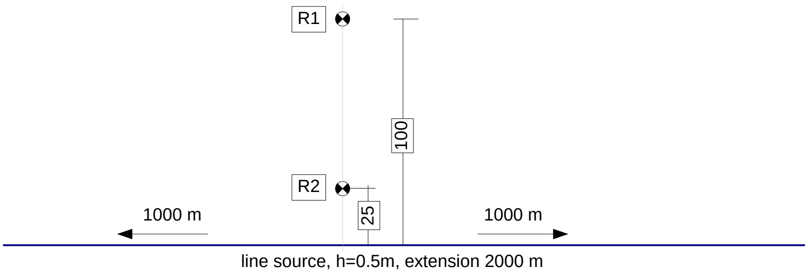

Figure 1 – Line source segment with two receivers

Constant length method is the simplest technique – the segment is subdivided in elements of length l with

$$l = k \cdot d \qquad (1)$$

and with d the shortest distance between the receiver and the line source (extended to infinity at both sides) and with k as input parameter. Figure 2 shows the distribution of calculation–rays – this is are straight lines connecting point sources and the receiver.

The calculated rays with k=0.1 producing a constant length of 10 m of all elements for the calculation at R1 shows figure 2.

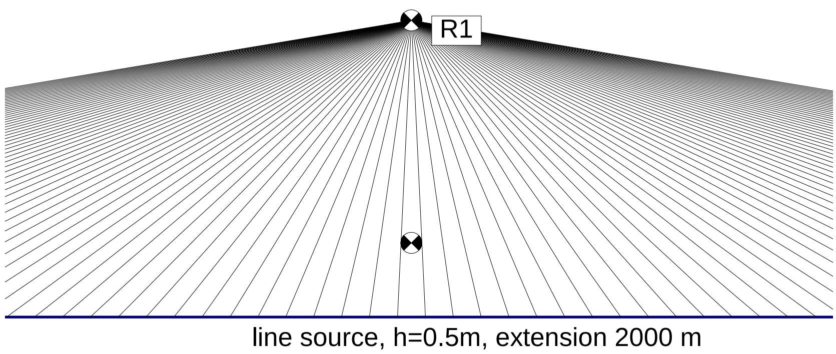

Figure 2 – Constant element length of 10 m – calculated rays for R1

The deviation of the calculated level from that one calculated with the extreme small elements with a length of 1 m is shown in figure 3 – this is in a certain way the error induced by the limited resolution due to the extension of the elements. Figure 4 shows the dependence between the selected parameter k and the number of calculations needed.

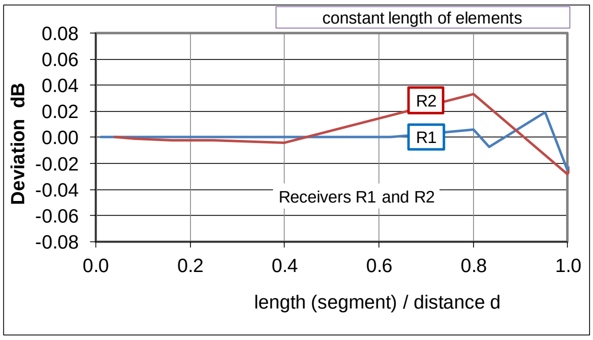

Figure 3 – Deviations caused by the size of the elements applying the constant length method

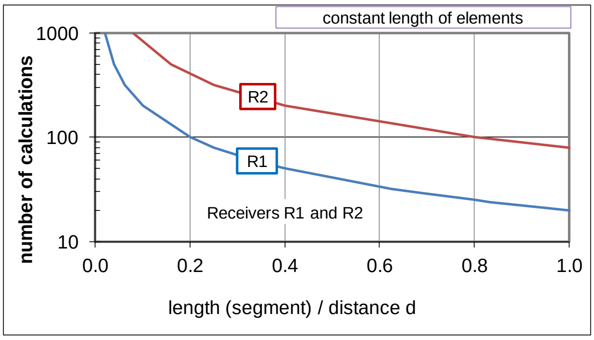

Figure 4 – Number of calculations needed with the constant length method

The accuracy of this technique of subdivision with constant element lengths is defined by the ratio of this length and the distance of the elements nearest to the receiver – the consequence is obviously a certain overkill of detailedness for the elements far away.

Dynamic subdivision are techniques where the size of the elements is defined by the same equation (1), but d is not the shortest distance from the receiver to the straight line through the line source segment but the distance of the receiver from the center of the element. These techniques produce different large elements of increasing size with increasing distance from the receiver.

The **“Recursion method”** is a technique where the size of each element is compared with the distance of its center from the receiver – if it is smaller than given by equation (1), the replacing point source is positioned at the center. If it is larger, it is subdivided into two parts of equal size and the comparison is repeated for both parts. This procedure is repeated recursively until all elements are in accordance with equation (1) and can be replaced by point sources. The size of the elements is not exactly in agreement with (1), but this equation defines an upper limit not exceeded. Figures 5 and 6 show the error caused by the finitely resolution and the necessary number of calculations.

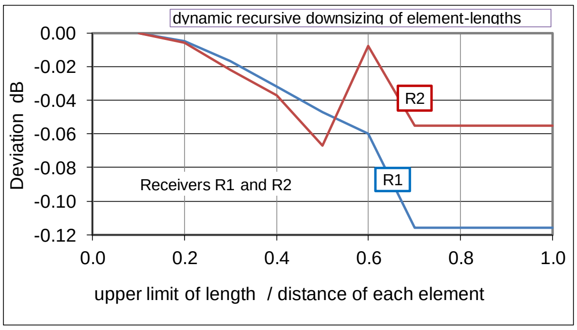

Figure 5 – Deviations caused by the size of the elements applying the recursion-method

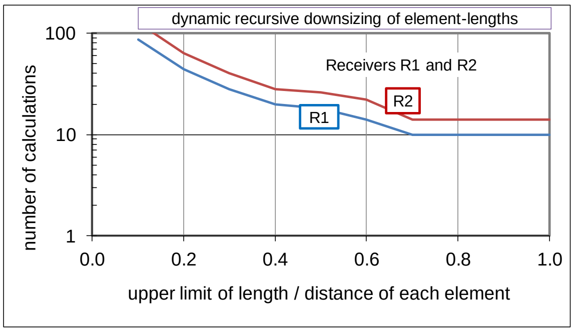

Figure 6 – Number of calculations needed with the recursion method

The **“RB-method”** according to (2) is also a very effective technique – the subdivision is started at the endpoint of the segment with the smaller distance to the receiver and the lengths of the elements are calculated sequentially. The length of all elements is exactly in accordance with (1), only the last element may be smaller. Figures 7 and 8 show the error caused by the finitely resolution and the necessary number of calculations.

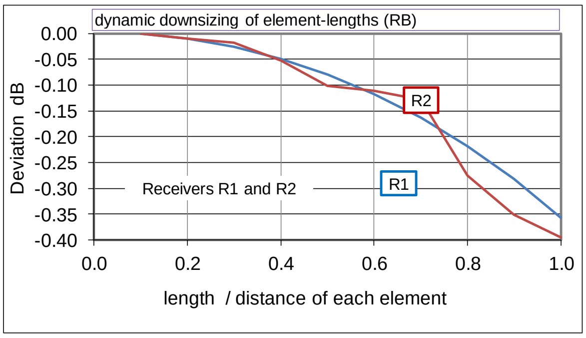

Figure 7 – Deviations caused by the size of the elements applying the RB-method

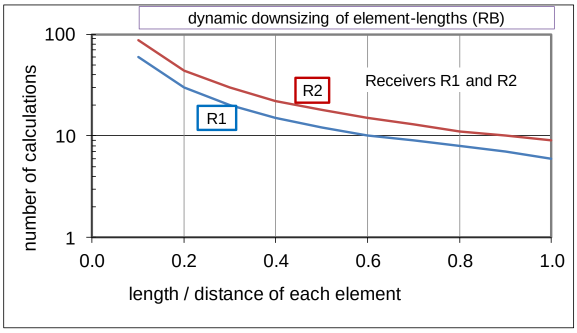

Figure 8 – Number of calculations needed with the RB-method

At a specified receiver position the deviation as a measure of the uncertainty can be related to the number of calculations needed. Figure 9 shows this dependency for receiver position R2. This type of presentation shows the advantage of the dynamic methods – while the constant length method shows an oscillating behavior with errors of some dB switching between plus and minus the deviation with the dynamic methods is only some tenth of a dB.

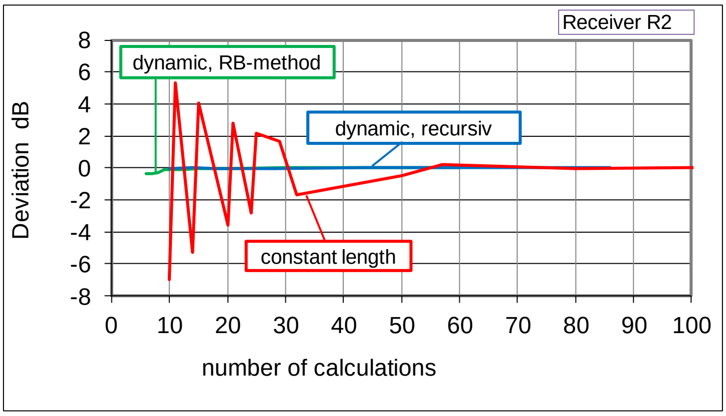

Figure 9 – Comparison of the methods by relating the deviations to the number of calculations

From these results it can be concluded that the constant length method is a waste of calculation time and that the dynamic subdivision should be preferred.

Things are getting more complicated if screening objects are blocking the direct propagation path.

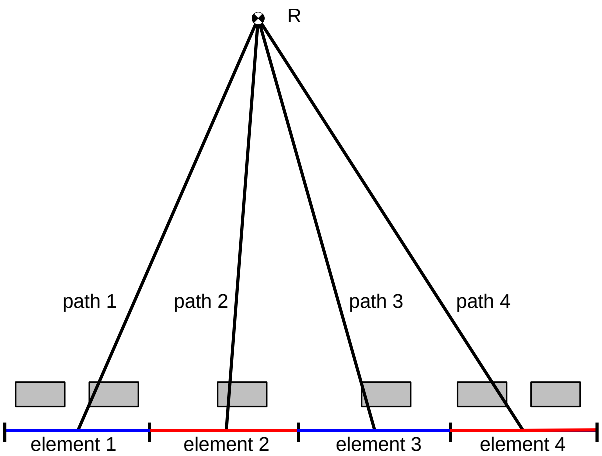

Figure 10 – A row of buildings between the line source and the receiver

If buildings or other screening objects are located between the extended source and the receiver as it is shown in figure 10, any strategy of subdivision oriented only at the relation between the distance and the extension of the element may produce erroneous results. Figure 10 shows the elements 1 to 4 produced by recursive subdivision – the ray paths produced by connecting the element centers with the receiver are all crossing a building and therefore the whole sound energy of each element is attenuated by diffraction – what is physically wrong because large parts of the sound energy can obviously propagate without being diffracted through the gaps between the houses.

Therefore with all built-up environments a 2-step procedure is needed.

The “projection method” is the subdivision of the line source by straight lines connecting the receiver with the relevant outer edges of all screening objects. Relevant means that the ray receiver-edge-source is not blocked by further screening edges. In Figure 11 the red elements are parts of the source radiating free to R without being attenuated by diffraction while the sound energy from the blue elements is screened.

These elements produced by the projection method may be too extended – therefore the dynamic subdivision method is applied with all elements in a second step as shown in figure 12. The black rays connect the receiver with the finally produced point sources replacing this line source.

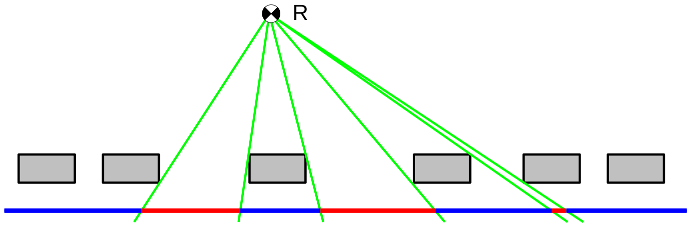

Figure 11 – Subdividing the line source by applying the projection method (first step)

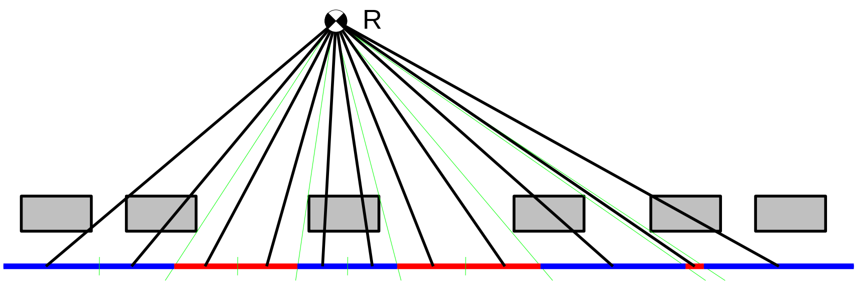

Figure 12 – Subdividing the elements further by applying the recursive method (second step)

To investigate the uncertainty that is related with certain strategies and parameter settings, one or two receiver positions as shown above are not enough – therefore we apply an arrangement of receivers distributed randomly in an area with extension larger than the typical gaps, as it is shown in Figure 13. The line source is extended ±200 m from the centerline, and the houses 20m x 10m x 10m are arranged with gaps of 10 m.

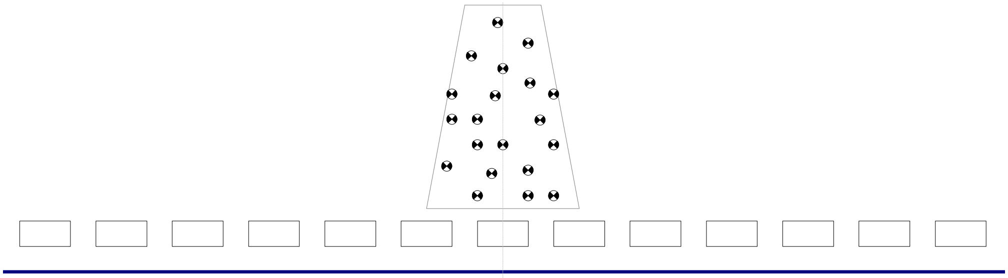

Figure 13 – Randomly distributed receivers behind a row of buildings with gaps of 10 m

In a first step only the dynamic subdivision of the line source with the RB-method is applied. The reference is a very fine resolution that we get with a value k = 0.01. Then increasing k values are applied and the difference of the calculation result to the reference value is determined for each receiver. The spread of these deviations at the 20 receivers is characterized by the standard deviation and can be shown as a function of the value k – see figure 14. Obviously the projection method is an effective but also necessary technique to reduce the otherwise very large level jumps from position to position.

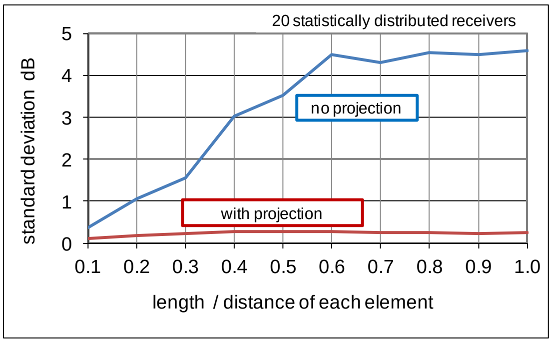

Figure 14 – The spread of deviations from the reference result over all receivers in dependence of the resolution k

It shall be mentioned that these techniques are different if the angle-scan method (3,4) is applied. With this method – nowadays applied to a lesser extent – search rays are sent from the receiver in constant angle intervals and sources as well as diffracting and reflecting objects are detected in a vertical cross section above these search rays. With this angle-scan-method such a "precise" strategy like projection is not possible and the only way to get more accurate results is to make the angle steps smaller. But obviously this procedure is limited due to acceptable calculation times.

To check the influence of these time consuming and therefore costly techniques on the final result we distribute 100 receivers randomly in a realistic environment as it is shown in figure 15.

Figure 15 – 100 receivers distributed randomly in a typical inner-city-environment

The location of the points is in accordance with the requirements formulated in (1).

If we calculate once with projection and once without projection, we get different results – these differences don't exceed 1 dB for 94% of all receivers, but the error without projection is -12 dB for one receiver, - 4 dB for another receiver and +2 dB for a third receiver. This is a very general aspect – the levels are nearly identical in mean, but at some few positions they can be very large. Mean value and standard deviation are not very helpful to describe such a distribution of deviations, if the method shall be applied to check the conformity with legal requirements.

The projection method is important to get the correct radiation through the gaps of the building facades at both sides of a road. On the other side the line source "road" will be "atomized" in extremely small elements if the propagation path crosses a larger distance of build up areas between source and receiver.

Balancing effort and effect it can be recommended to apply the projection method only with receivers up to a maximal distance of 100 m from the segment of the road under test. There may be special cases where a building block with a gap in large distance from a road is the only object disturbing free propagation and where the recommended restriction may cause relevant errors, but these are extremely seldom and can be neglected in many cases, e.g. if levels are calculated for noise mapping purposes. But taking into account the obviously large differences caused by an inadequate subdivision it is highly recommended to include a clear specification about the maximal projection distance in the description of a method that shall be applied in legal issues and that shall be implemented quality assured in different software products.

3. REFLECTING AND SCREENING OBJECTS WITH EXTENDED SOURCES

Independent of the calculation method applied – with ray based engineering methods reflections are generally calculated applying the image source method. It is based on the assumption that the reflecting surface is "acoustically" flat, acts like a mirror in optics and can be replaced by an additional source in a mirrored position.

The contribution of sound reflected at building facades near extended sources needs also the application of the projection method to be evaluated correctly. Figure 16 shows an example with a road as line source, a receiver R and two buildings B1 and B2 with different size at the opposite side.

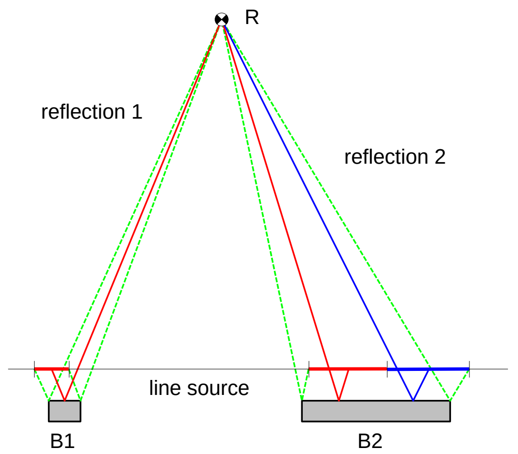

Figure 16 – The application of the projection method with reflected sound

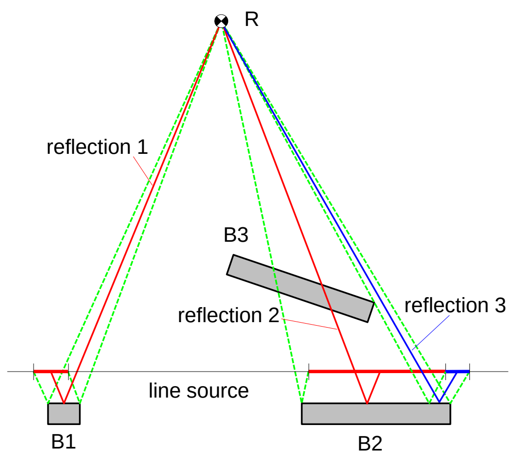

Figure 17 – Projection of reflected sound with screening object

The subdivision of the line source is dependent on the extension of the reflecting surfaces. The sound reflected by building B1 is bounded by the two dashed green lines and therefore only the sound power of the red element of the line source can influence the receiver and is therefore applied as source emission to calculate this contribution on the red colored ray path. Building B2 is so large that the source element produced by projection – also bounded by two dashed green lines - is further subdivided in the second step applying the recursion method and two ray paths are applied to calculate the contribution of the reflection at B2.

If a screening object like building B3 (figure 17) intersects the area covered by the reflected sound wave these different propagation conditions are taken into account by a further subdivision producing two line source elements.

These are only some of the many additional commitments that have to be agreed on if noise prediction methods shall produce the same result if they are implemented in different software products. Some practical examples taken from the built-up scenario shown in figure 15 where unacceptable errors arise if the two step procedure including projection is not applied are shown with figures 18 to 21.

The reflected ray path in figure 18 is found with and without projection, but in the latter case the whole energy of the segment is transmitted, while the gap limits this transferred energy. The resulting error is + 2 dB. The path shown in figure 19 is only found with projection – without projection no ray path crosses the gap and therefore the free propagating sound energy is not taken into account – the resulting error is -4 dB.

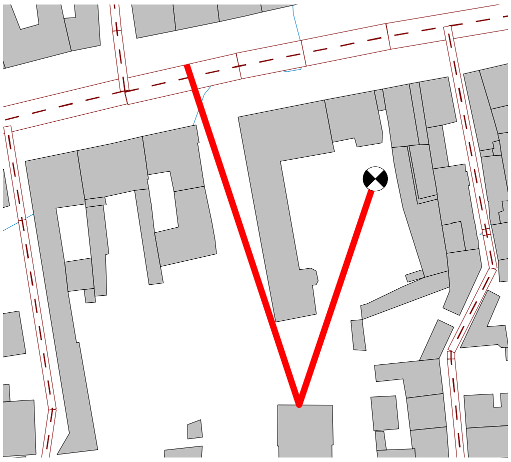

Figure 18 – Ray path with a deviation of + 2 dB if projection is not applied

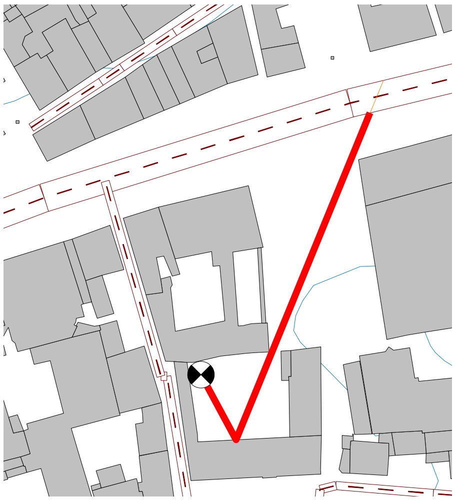

Figure 19 – Receiver with a deviation of - 4 dB if projection is not applied (the path shown is not detected without projection)

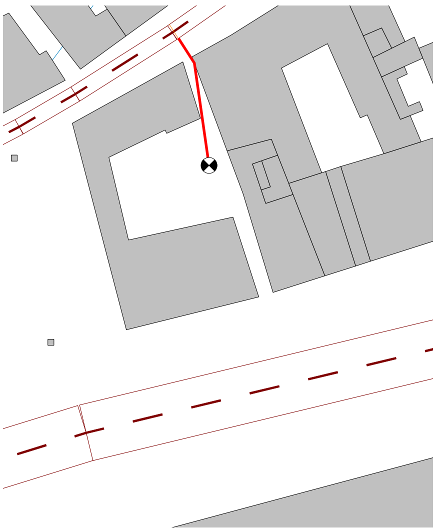

Figure 20 – Receiver with a deviation of - 12 dB if projection is not applied (only the path shown is detected without projection)

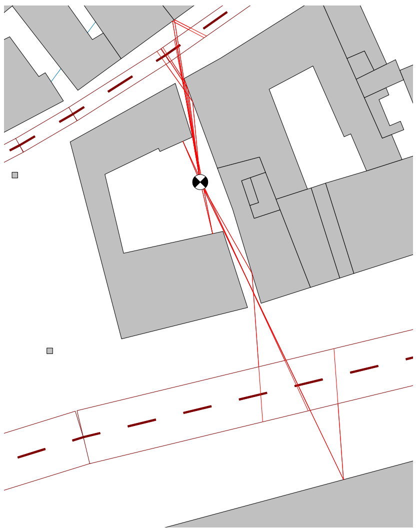

Figure 21 – same as figure 18, but paths detected with projection (the paths shown include reflection of 1st order not detected without projection)

Figures 20 and 21 demonstrate an example where the error caused by not applying the projection method is 12 dB. Without projection only the path shown in figure 20 is found, and its contribution has nothing to do with the breadth of the gap. Applying projection many more possible ray paths through the gaps are found and their contributions are geometrically derived from the breadth of the relevant gaps. (In all these figures only the ray-paths are shown that are not screened).

All the examples above are shown in top-view, because sound propagation through tightly built-up areas is mainly determined by vertical reflecting surfaces. But in many cases like backyards or other spaces surrounded by buildings only diffracted sound reaches the receiver where the noise level shall be predicted. Therefore a lot of further techniques and specifications are necessary to solve these cases where combined effects occur like the diffraction of reflected sound and the reflection of diffracted sound.

4. MULTIREFLECTION IN STREET CANYONS

The calculation of reflections up to high orders is extremely time consuming and should be avoided if projects are large with hundreds or even thousands of buildings. To calculate the sound levels in street canyons where both sides of a road are flanked by closed facades it is a well proven technique to calculate reflections only up to the first or second order and to add to the road emission a correction for multi-reflection.

Figure 22 – Street canyon with acoustically smooth facades

Figure 23 – Structured and diffuse reflecting facades

If a source is radiating at a certain position in such a street canyon and we measure the sound level in dependence of the distance source – receiver, the levels are influenced by these multi-reflections between the facades. With acoustically smooth facades as shown in figure 22 the level increase caused by the facades increases with increasing distance, while it shows a maximum near the source and decreases with increasing distances if the facades are structured and reflecting diffuse as shown in figure 23.

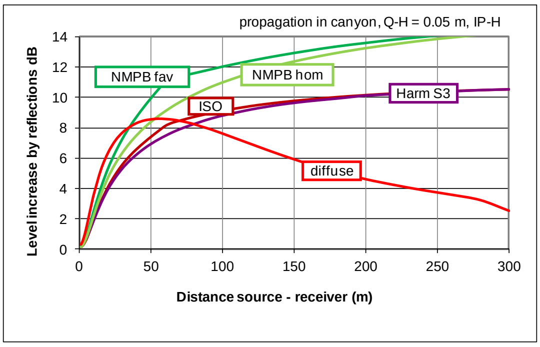

Figure 24 – Level increase calculated with different standardized methods (Harmonoise, NMPB and ISO 9613-2) applying mirror image method and with a radiosity model for diffuse reflections.

The curves in figure 24 show the difference of levels calculated with the method under test once with and once without flanking facades with an absorption coefficient of 0.1.

The difference between specular and diffuse reflection is by far smaller if the influence of the flanking buildings on the equivalent sound pressure level caused by the source “road” is calculated. Figure 25 shows the level increase caused by the flanking facades in dependence of the facades distance for different receiver heights in front of such a façade. These investigations about the noise in street canyons are published in (5).

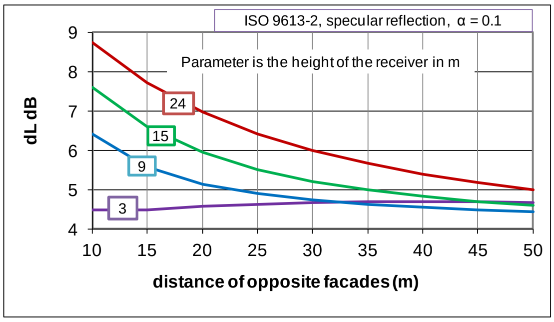

Figure 25 – Level increase caused by flanking facades if these reflect specular

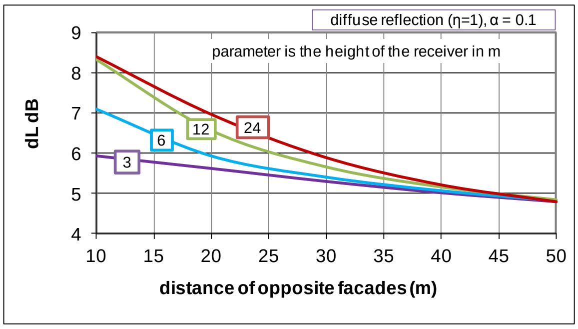

Figure 26 – Level increase caused by flanking facades if these reflect diffusely

5. CONCLUSIONS

Taking into account these many purely geometric problems that influence the accuracy of calculated sound levels in built-up areas by far more than meteorological effects or other scientifically interesting phenomena a new approach in standardization seems to be necessary. Nearly all standards and guidelines neglect these problems arising if the described method shall be implemented in software.

Therefore it is a question of quality assurance to treat and solve them if the method shall be applied in all possible environments. A first step in this direction could be the approach of the ISO 17534 – series, where such specifications can be added as “Additional Recommendations” in method specific Technical Reports.

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