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Reflected sound in street canyons – diffuse or specular?

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Sound reflections at building facades are generally calculated applying the mirror image method and therefore it is assumed generally that specular reflections occur. But in many cases of structured surfaces with balconies, jutties and other irregularities these facades are obviously not acoustically plain and therefore diffuse reflections may occur. With financial support by the German BAST (Bundesanstalt für Straßenwesen) the differences of specular and diffuse reflections with respect to road traffic noise in street canyons and in other tight built up areas have been investigated. Background was to get a better knowledge about the uncertainties of possible software strategies and to take the level increases caused by high order reflections in street canyons into account in noise calculations. Experimental and theoretical findings with respect to time dependent sound pressure levels and equivalent continuous sound pressure levels are presented and discussed.

1 INTRODUCTION

Due to an intended revision of the German calculation method for road traffic noise the method how to account for the level increase caused by multi-reflections in street canyons should be investigated. In the existing method noise levels are generally calculated taking into account first order reflections in detail by applying the mirror image method on the existing reflecting surfaces like flanking facades. The additional level increase caused by reflections between the parallel facades is taken into account by a correction D_{refl}, being a simple function of the distance and height of the opposed facades. It was a subtask to check if the assumption of acoustically plane facades with specular reflections will produce different results than structured facades with diffuse reflections. Recommendations how to treat such multi-reflections in the frame of a revision of the calculation method should be given.

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2 METHOD

The general method was to apply the calculation method with detailed tracing of reflections up to high orders. The results can be compared with those obtained using the RLS-90 approximation

with the correction D_{refl} and to quantify the uncertainties and systematic deviations introduced by neglecting the geometrical and acoustical parameters in detail.
The necessary calculations were performed with the software CadnaA to apply the methods RLS-90, ISO 9613-2, NMPB 2008 (French) and others. A not commercially available software developed especially for such investigations with diffuse reflections was used to apply the Radiosity method.
With specular reflections incident and reflected ray show the same angle with the reflecting surface. With diffuse reflecting surfaces the reflected energy is distributed according to

$$J = \frac{P}{2\pi r^2} \cdot (1+\eta) \cdot cos^{\eta}(\delta) \qquad (1)$$

with
J sound intensity at the receiver
P total sound power radiated
r distance radiating element - receiver
η directivity exponent of the radiation (1 according to Lamberts law)
δ angle ray – normal of radiating surface

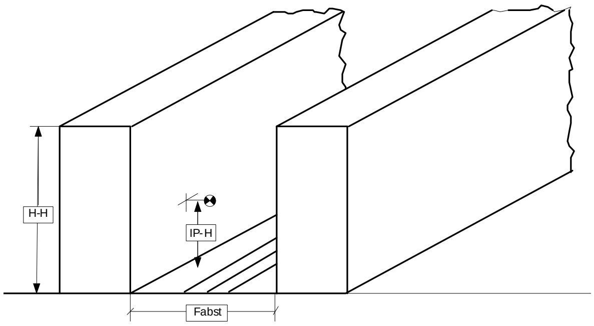

Fig. 1 - Model of a street canyon

A model of the street canyon was created where the paramaters distance, height and absorption of the facades and height of the receiver position could be varied.
Additionally some measurements have been performed, but these are only a starting point to test the procedure – they should be continued because they are the only and real validation of all assumptions included in the calculations.
It was the aim of this investigation to show up the pros and cons of three general methods. The first two are to calculate the level increase as a parametric correction to be added to noise levels calculated under free field conditions or by taking into account one reflection for the relevant reflecting surfaces (1^{st} order reflections).
Such a correction can be independent of the detailed receiver position, like it is the case with D_{refl} of RLS-90 – it can be applied like an increase of the emission of the source and is therefore a very simple solution.
The second method is to construct a similar correction, but using the receiver height as functional parameter. It must be evaluated if the increase of accuracy balances the disadvantage that the correction cannot further be added to the emission and the problem how to treat this level increase inside the canyon in calculations where the level outside shall be determined.

A third method is to perform the calculations up to high reflection orders without any approximation. Applicable strategies must be shown up because the ray construction with pure mirror image method will “explode” if many buildings and façade elements are included. The “Angle-Scanning-Method” on the other side does not allow calculating even low order reflections caused by reflectors near the source if many buildings are located between source and receiver.

3 MAJOR RESULTS

In a first step the sound decay along the center- line of the street canyon away from a small source (or 1 m piece of road) was determined applying different methods. The distance of the facades is 20 m. The levels are normalized by subtracting the free field level according to

$$L = L_{calc} - \left(L_W - 11 - 20log\left(\frac{r}{r_0}\right)\right) \qquad (2)$$

with

L_W Source sound power level
r distance source - receiver
r_0 reference distance 1 m

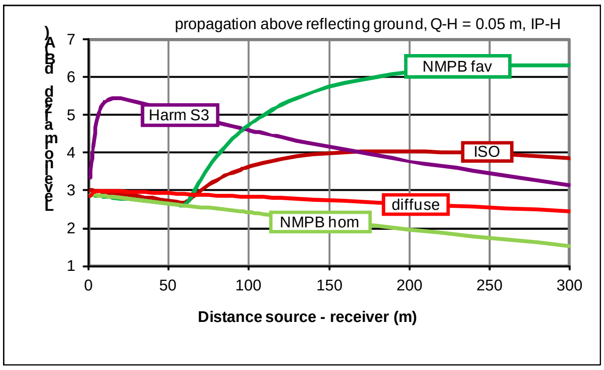

Fig. 2 - Direct sound and ground reflection

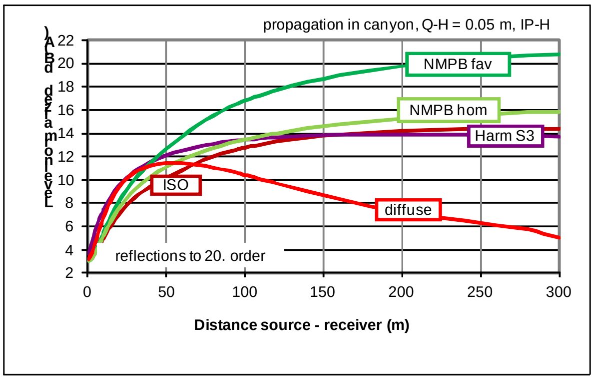

Fig. 3 - Total level with reflections up to 10th order

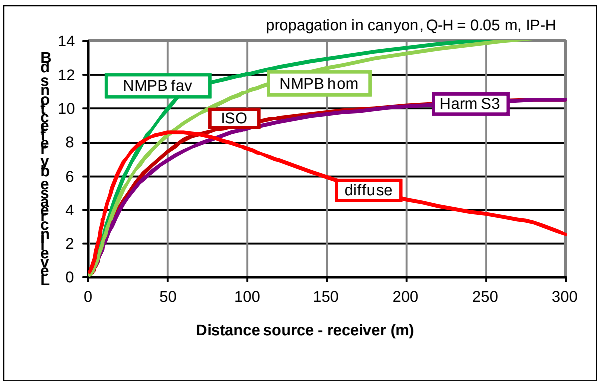

Fig. 4 - Level increase caused by reflections

Figure 2 shows the difference in free field propagation with different calculation methods applied. The increase of these levels caused by the facades shown in Figure 5 reaches a maximum at 50 m distance for diffuse reflections. With specular reflections the range of influence is not limited – the level increase is above 10 dB in 300 m distance.

The same situation was checked with some orienting measurements. The level increases resulting from the measurement in the 20 m broad street canyon (Fig. 5) are shown in figure 6 and compared with the values according to calculations.

Fig. 5 - Street canyon where measurements where made

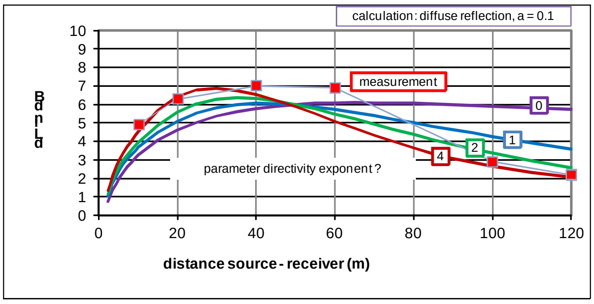

Fig. 6 - Comparison of measured and calculated levels

These some measurements indicate in the near vicinity of the source specularly, in other parts more far diffusely reflecting facades.

To investigate the increase of timely averaged L_{eq} levels the complete road was modeled as a line source 0.05 m above ground.

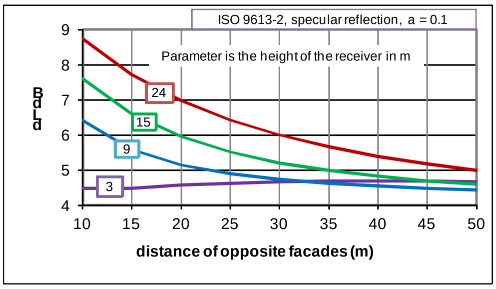

Fig. 7 - Level increase caused by specular reflections

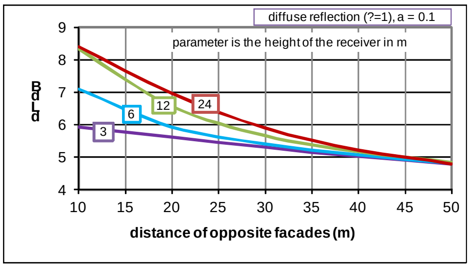

Fig. 8 - Level increase caused by diffuse reflections

The results (Fig. 7 and 8) show a strong dependency of the reflection induced increase of level and the height of the receiver. The difference resulting from the structure of the facades – specularly or diffusely reflecting – is negligible if realistic distances between facades (> 20 m) are taken into account.

The model shown in figure 9 was used to check the influence of gaps between the buildings at each side of a road.

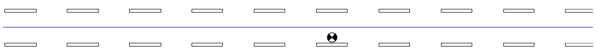

Fig. 9 - Modeling the flanking facades with gaps

The diagram figure 10 is only one example of the results – it shows the dependency of the level increase caused by specular reflecting facades from the percentage of gaps.

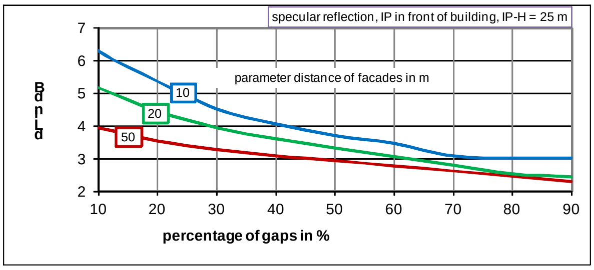

Fig. 10 - Level increase in dependence of the percentage of gaps

The length of this part of the façade with gaps was varied to check the extension of the façade that must be taken into account in determining this percentage (figure 11).

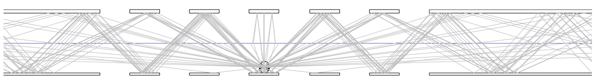

Fig. 11 - Model with variable length of façade with 50% gaps

The results – presented in more detail in the main report[1] – showed that with specular reflecting facades the percentage of gaps should be determined by taking into account about ± 125 m at both sides of the receiver. With diffusely reflecting facades this relevant extension is ± 50 m.
All these relations shown for the level increase dL caused by reflections are also presented in the main report related to the increase of the level above its value calculated with 1st order reflections included – this is the correction for multi-reflection D_{refl}. This correction D_{refl} can be expressed as a function of the ratio receiver height / distance of facades.

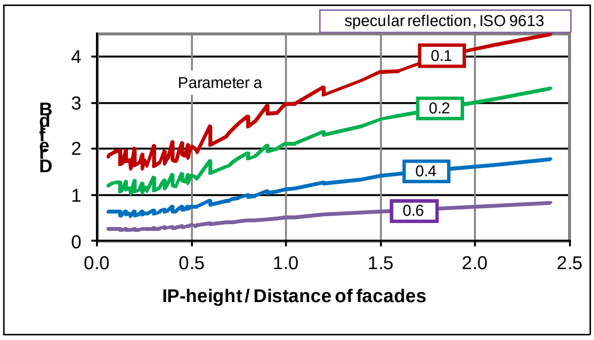

Fig. 12 - Correction for multi-reflections versus h' for different absorption coefficients

With an absorption coefficient 0.1 recommended for modeling of facades the value of D_{refl} can be expressed as

$$D_{refl} = \left(1{,}8 * h'^2 - 0{,}5 * h' + 1{,}8\right)\, dB \qquad (3)$$

with

$$h' = \frac{Receiver\ height}{Distance\ of\ facades}$$

But in case such a correction dependent on the height of the receiver shall be applied a solution must be found how to take this spatial varying D_{refl} into account if levels outside the street canyon shall be calculated.
This latter problem can be solved with a third approach – the detailed calculation of reflections up to about 10th order.
There are two main strategies of ray based calculation of sound levels in existing engineering models – the projection method with mirror images (RT) and the Angle-Scanning method (AS) starting search rays from the receiver position. These techniques are discussed in Annex B of the report.
The RT-method is more accurate because spatially varying propagation conditions are taken into account in the sub-partitioning of extended sources like roads with the projection method. Further it is complete in the sense that all possible reflections can be found. The calculation of reflections can be restricted to reflecting surfaces up to a definable maximal distance around source and receiver. The main shortcoming: Calculation times explode with increasing number of reflecting objects and increasing order of reflections to be taken into account. It is absolutely impossible for an agglomeration with hundreds or even thousands of buildings to calculate reflections up to order 10 – the requirement for street canyons.
The resolution and the accuracy of AS-method depend on the number of search rays and therefore the method is generally less accurate. It detects reflecting surfaces starting from the receiver,

but it does not find even the important first order reflections near the source if many objects are located between source and receiver. But it is easy to find reflecting surfaces around the receiver if no other objects are crossed by the search ray.

The most accurate and quick solution for agglomerations developed in the frame of this project is to apply a mixed strategy – the HPF-method (**H**ybrid **P**ath **F**inding method):

The calculation including 1st order reflections is performed applying the projection method (RT) – the detection of reflecting surfaces can be restricted to about 100 m around source and receiver. Additionally the AS-method is applied to calculate reflections from 2nd up to about 10th order with the definition of the reflection depth (the number of reflectors that split the search ray in one progressing and one reflected ray) of value 1.

These two contributions are added energetically. The method minimizes the uncertainties connected with non detected reflections. But even this HPF method shows some severe shortcomings if noise maps with dense built up areas are calculated – therefore it may be advantageous to keep the method of calculating one reflection order in detail and to account for higher orders with a correction similar to D_{refl}. This is especially recommended for calculations in a legal framework where high reproducibility is important.

4 REFERENCES

1. Probst W.: "Straßenlärm bei dichter Randbebauung – Untersuchungen zur reflexionsbedingten Pegelerhöhung (Investigation of the increase of noise levels caused by reflections in street canyons)", to be published soon by BAST (Bundesanstalt für Straßenwesen), 2012.