PREDICTING SOUND LEVELS BEHIND BUILDINGS - HOW MANY REFLECTIONS SHOULD I USE?

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1 ABSTRACT

Sound level prediction is an important issue for noise assessment. When calculating the sound level with Standards such as ISO 9613-2 reflections from vertical obstacles often dominate the accuracy for shielded locations. These locations may be sensitive residential areas hidden behind a cluster of industrial buildings or behind one or more noise barriers. Some commercial software such as Cadna/A and Soundplan offer options to control the number of reflections by users. However, increasing the number of reflections requires more calculating time and might not lead to more accurate prediction. The accuracy of applying different numbers of reflections is compared by using theoretical calculations and simulations of the ray/ beam tracing method in Cadna/A; variables include different height of obstacles and varied topologies of the obstacles or buildings. This study recommends the number of reflections for different building topologies if the ISO 9613-2 propagation model is used for sound level prediction.

2 INTRODUCTION

The main parameters affecting the accuracy of the sound level prediction outdoor are the direct sound, the reflected sound, the diffracted sound and the scattered sound due to turbulence. Direct sound transmission is calculated where there is an uninterrupted line of sight between a sound source and a receiver position. In this case, the sound pressure level at the receiver positions may be calculated simply based on attenuation due to distance. Reflected, diffracted and scattered sound is often more difficult to predict, especially when the topology is complicated.

Theoretical models are typically used with far fewer physical details than occur in the real world. Engineering models need to balance complicity and accuracy to predict sound levels in a practical manner. The ISO 9613-2[1] is one of the widely used models to calculate sound propagation outdoors. In ISO 9613-2 the attenuation is considered as the contribution of the attenuation effects. The total attenuation is the arithmetic sum of the contributions from all the effects:

$$A = A_{\mathrm{div}} + A_{\mathrm{atm}} + A_{\mathrm{gr}} + A_{\mathrm{bar}} + A_{\mathrm{misc}}$$

where, A is the total attenuation in dB, A_{div} is the attenuation due to geometrical divergence; A_{atm} is the attenuation due to atmospheric absorption; A_{gr} is the attenuation due to ground effect; A_{bar} is the attenuation due to a barrier; A_{misc} is the attenuation due to miscellaneous other effects. The prediction errors can be quantified and analysed for each attenuation component.

Some software has been developed based on the principle of the ISO 9613-2 standard, such as Cadna/A[2] and SoundPlan[3]. In the software, sound is modelled as many rays radiating from each source; the geometrical relation between every source, obstacles and receivers are determined by these rays. The above mentioned attenuations can therefore be calculated by these geometrical relations and the source power level. Compared with the attenuation due to the geometrical divergence, A_{div}, other attenuations are often much less accurately predicted. In this article, the attenuation due to a barrier, A_{bar} and the number of reflections are discussed. The effect of the atmosphere, A_{atm} is not important compared with A_{div} and A_{bar}, when calculating over distances less than 500 m, for example.

The ISO 9613-2 method can be used for noise mapping or sound level prediction at the nearest sound sensitive receptors. For noise mapping, increasing the number of reflections would significantly increase the calculating time; one or two reflections are typically used based on the scale and density of receivers. For sound level prediction of a few receptors, different topologies may vary from each other.

3 TOPOLOGIES AND SOUND SOURCES

3.1 Typical topologies

Two typical topologies are used to in this study, where they are extracted from city of Newcastle. The satellite map images are shown in Figure 1 and Figure 2.

Figure 1: Satellite map of dense community

Figure 2: Satellite map of sparse community

The corresponding abstracted calculation models in Cadna/A are shown in **Figure 3**.

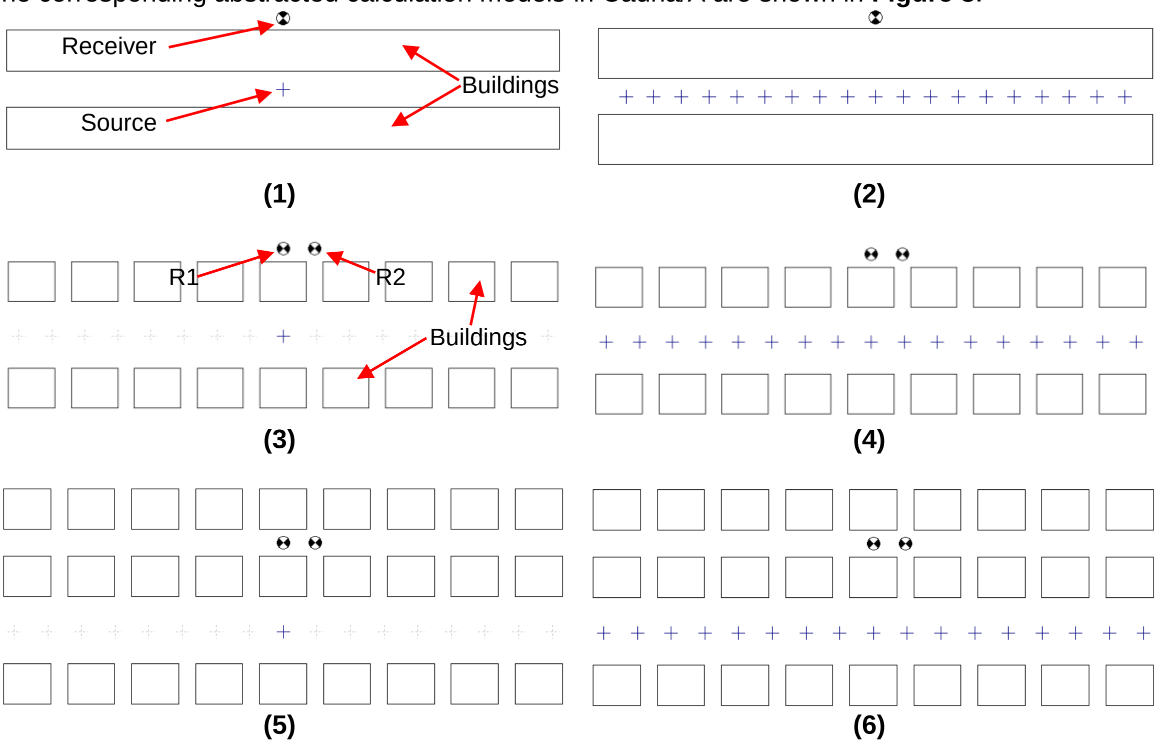

Figure 3: Abstracted calculation situations.

For situations in Figure 3 (1) and (2), terraced houses mean the sound cannot directly reach the receivers from the source. The main contribution to the sound pressure level at the receiver positions is due to the sound diffracted over the roof top. For situations in Figure 3 (3), (4), (5) and

(6), sound energy may reach the receivers by direct sound, or reflected sound in the horizontal plane as well as diffracted sound in the vertical plane.

3.2 Model details

Two arrangements of sound sources are considered. The first one is a single point source which may represent one unit of mechanical plant. The other one is a line of point sources which may represent traffic on a road. The street width is 13 m and the sources are in the middle of the street. The building width is 15 m. The source power levels of all sources are 100 dB and the calculation is undertaken at 500 Hz only. All other parameters for different situations are shown in Table 1.

Table 1: Parameters used in different situations

Situation	Source height	Receiver height	Source from façade	Receiver from façade	Loss per reflection	Building height
(1), (2)	0.5 m	1.5 m	6.5 m	3 m and 10 m	1 dB	3 m, 6 m, 10 m
(3), (4), (5), (6)	0.5 m	1.5 m	6.5 m	3 m	1 dB	6 m

To calculate the diffracted sound pressure level, Pierce's method is well-known and widely validated[4,5]. Pierce's method is therefore considered as the true value in this article. Figure 4 shows the difference of insertion loss between ISO 9613 and Pierce's method. It is noted that the diffracted sound energy in the ISO 9613-2 model is overestimated compared with Pierce's solution. For frequencies above 500 Hz, the difference could reach 20 dB. Figure 4 illustrates the maximum threshold attenuation due to a wide barrier in the ISO 9613-2 model of 25 dB.

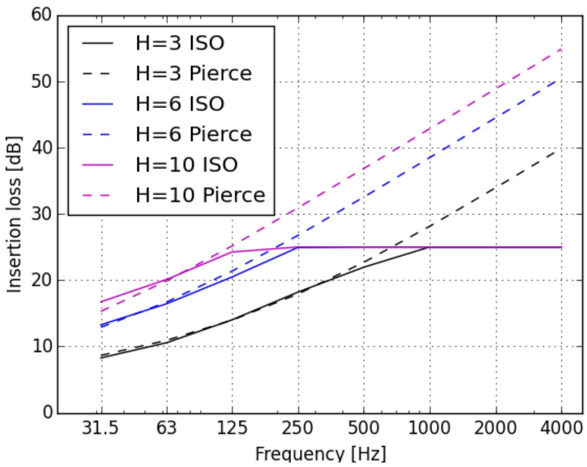

Figure 4: Difference of insertion loss. H indicates the height of the barrier; the width of the barrier is 15 m; the distance from the source to the barrier is 6.5 m; the source height is 0.5 m; the receiver height is 1.5 m and the distance from the receiver to the barrier is 3 m.

If the main contribution to the receiver level is due to diffraction, such as for situations (1) and (2), a few reflections in the ISO 9613-2 model may result in an equivalent effect of many reflections in the theoretical solutions. For situations in (3), (4), (5) and (6), the major contribution is from the reflections in the horizontal plane; in this case, the overestimation of the ISO 9613-2 diffraction method can be neglected. Therefore, the model strategy is concluded as follows:

- For situation (1), (2), compare ISO 9613-2 and Pierce's solutions for different reflections to determine the proper number of reflections for a dense community topology.
- For situation (3), (4), (5) and (6), use ISO 9613-2 method to validate the number of reflections when the sound pressure levels start to saturate. In the examples below, the ISO 9613-2 model is implemented in the Cadna/A software.

4 RESULTS ANALYSIS

4.1 Situation (1)

The change of sound pressure level due to different numbers of reflections are analysed for the above mentioned situations. Figure 5 and Figure 6 show the level increase for situation (1) with the receiver 3 m and 10 m away from the building façade. It is shown that if the receiver is close to the façade, such as 3 m, even there are no reflections, the predicted level of the ISO 9613-2 model is much greater than that of Pierce’s model. The difference can be more than 10 dB for the building height 10 m. If the distance from the receiver to the façade is up to 10 m, except for very low buildings, such as 3 m building, the diffracted sound pressure level of ISO 9613-2 is still much higher than that of the Pierce’s model, due to the threshold attenuation applied in ISO 9613-2. Hence no reflections or a small number of reflections may be appropriate if the receiver is completely shielded by buildings.

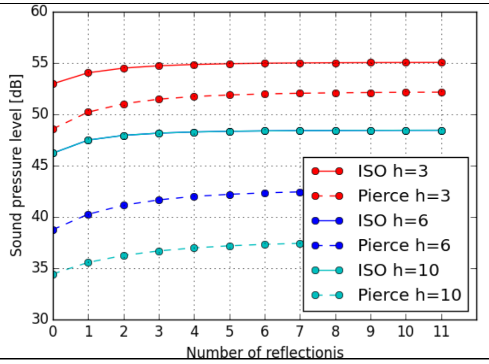

Figure 5: Situation (1) 3 m from the façade

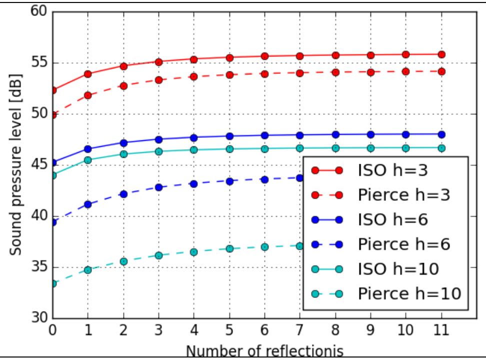

Figure 6: Situation (1) 10 m from the façade

4.2 Situation (2)

Figure 7 and Figure 8 show the relation between the predicted sound pressure level and the number of reflections. The most significant difference with situation (1) is the predicted levels of ISO 9613-2 method and the Pierce’s method intersect each other for the 3 m high building.

Therefore if the relative height between the building and the receiver is less than 2 m, more than four reflections may be appropriate. If the relative height is greater than 4.5 m, fewer than two reflections may be suitable. It is noted that the threshold of the relative height is difficult to determine; therefore a general value of three reflections may be used for single or two storey buildings.

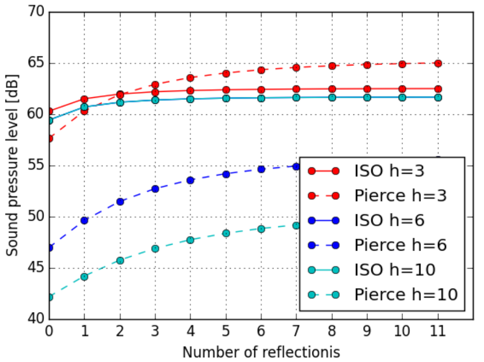

Figure 7: Situation (2) 3 m from the façade

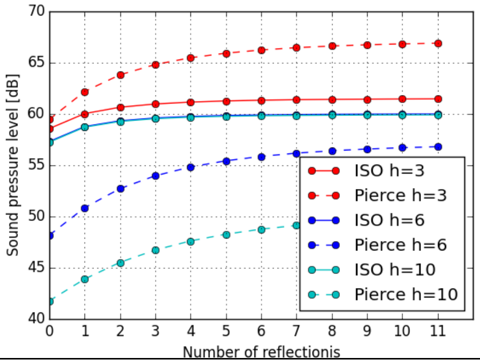

Figure 8: Situation (2) 10 m from the façade

4.3 Situation (3), (4), (5) and (6)

For situations (3), (4), (5) and (6) the reflections in the horizontal plane dominate the sound pressure levels at the receiver position; more reflections are required to calculate a level closer to the true value. However, the capability of the computer may limit the choice of number of reflections. In most cases from Figure 9 to Figure 12, the sound pressure level saturates after four reflections. Therefore, for the situations dominated by the horizontal reflections, at least four reflections are recommended.

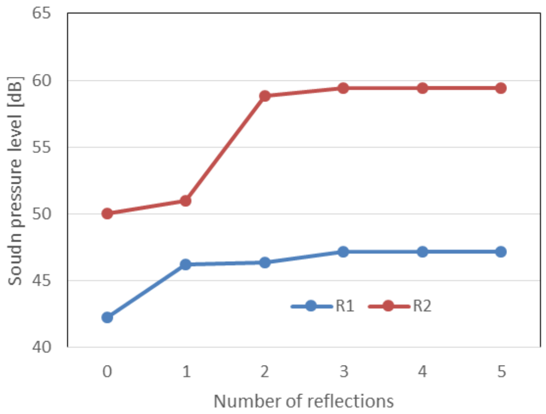

Figure 9: Situation (3)

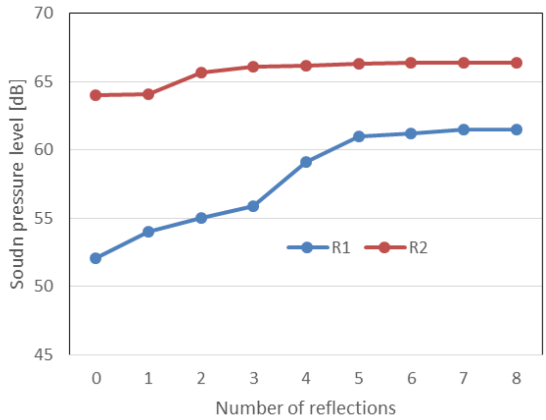

Figure 10: Situation (4)

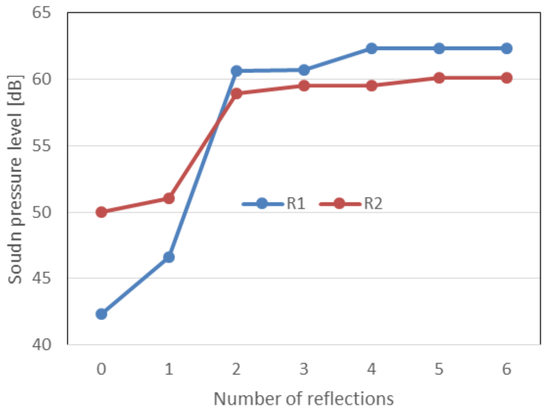

Figure 11: Situation (5)

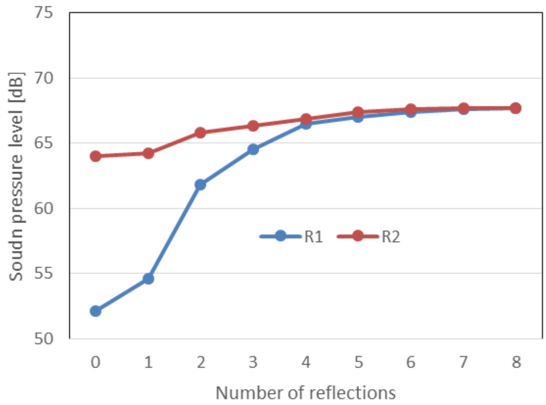

Figure 12: Situation (6)

4.4 Discussion of small objects

In ISO 9613-2, reflections are only considered when the following requirements are met: 1) a specular reflection can be constructed; 2) the magnitude of the sound reflection coefficient is greater than 0.2; 3) the surface is large enough which means the following equation should be satisfied.

$$\frac{1}{\lambda} > \frac{2}{(l_{\min} \cos \beta)^{2}} \frac{d_{s,o} d_{o,r}}{d_{s,o} + d_{o,r}}$$

Where λ is wave length; l_{min} is the minimum dimension of an object; $d_{s,o}$ is the distance between the source and the reflection point; $d_{o,r}$ is the distance between the reflection point and the receiver; β is the incidence angle. Details can be found in the ISO 9613-2 standard.

These parameters vary significantly for different situations. To quantify the potential effect of this principle to the modelling in software, it is assume that the specular reflection can be constructed;

the reflection coefficient is greater than 0.2; $d_{s,o} = d_{o,r}$; the sound speed is 340 m/s and the range of other parameters are shown in Table 2.

Table 2: Ranges of parameters

	β degree	l_{min} m	Frequency Hz	$d_{s,o}$ m
Range	15, 45 and 75	0.5, 1.0, 1.5, 3.0, 6.0, and 9.0	125 to 4000 octave band centre frequency	1 to 20

Based on the above assumptions, the third reflection criteria can be checked. The initial value *N* for each wave length and each l_{min} is set to zero. For each wave length and each l_{min} the other parameters combined with each other. If the third criteria is satisfied, one is added to the initial value *N*. In this way, for a specific wave length and l_{min}, the number *N* indicates the chance of satisfying the third criteria. The bigger this number *N*, the higher chance a reflection may be included. Figure 13 shows the results of *N* in relation of wave length and l_{min}. The radius is the value of *N*.

For 500 Hz (wave length is 0.68 m), the reflection of an object with l_{min}<2 m is unlike to be included in the reflection calculation. Therefore, the roughness of the buildings may be considered by the reflection coefficient instead of modelling them as edges.

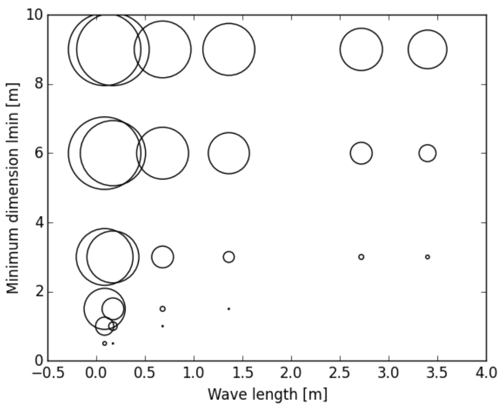

Figure 13: The opportunity ISO 9613-2 considering as a reflection

5 CONCLUSIONS AND DISCUSSIONS

The potential number of reflections for common situations is compared. Results show that where vertical diffraction dominates sound transmission, a small number of reflections are sufficient. Where horizontal reflections dominate sound transmission, at least four reflections should be used. It is noted that the comparisons in this article are based on calculations at 500 Hz. If the source is wide band, the results might be slightly different with that presented.

Including the building details in the modelling may result in underestimation of the reflections.

6 REFERENCES

1. ISO 9613-2:1996, Acoustics -- Attenuation of sound during propagation outdoors -- Part 2: General method of calculation.
2. Cadna/A software manual, version 4.5, 2014.
3. SoundPlan User manual, version 7.1, 2012
4. A.D. Pierce, Diffraction of sound around corners and over wide barriers, J. Acoust. Soc. Am., 55, 1974, 941-955.
5. W. Wei, D. Botteldooren, T. Van Renterghem, M. Hornikx,J. Forssén,E. Salomons, M. Ögren, Urban Background Noise Mapping: The General Model, Acta Acustica united with Acustica, Volume 100, Number 6, November / December 2014,1098-1111(14)