Traffic noise in shielded urban areas: comparison of experimental data with model results

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Noise maps of cities are commonly produced with rather simple engineering models for sound propagation. These models may be inaccurate in complex urban situations, in particular in situations with street canyons. Street canyons are urban areas that are partly or completely enclosed by buildings, for example a street between two buildings or a backyard surrounded by buildings. In this paper we study sound propagation from a city bus in a street canyon to a receiver in a nearby street canyon. Multiple reflections of sound waves in both the source canyon and the receiver canyon play an important role in the sound propagation. Experimental data are compared with three types of model results: i) results of a numerical boundary element model, ii) results of a 1:30 scale model experiment in a semi-anechoic room, and iii) results of the Dutch standard engineering model, which is similar to the international standard ISO 9613-2. The data are in reasonable agreement with model results i) and ii), while the engineering model yields sound levels that are about 6 dB too low.

Keywords: urban noise, street canyons, sound propagation, noise measurements and prediction, numerical models, scale modelling, engineering model.

1 Introduction

Traffic noise in cities is a major environmental problem. The European Union has decided that all large European cities have to produce *noise maps*, which show the distributions of noise levels in the cities. In a next stage, the cities have to make *action plans* to reduce the noise at locations where the levels are too high.

The noise maps are based on computer calculations, taking into account all noise sources. For the propagation of sound in a city, one usually employs a rather simple engineering model. Locally these calculations may be inaccurate, for example at locations that are shielded by buildings, such as courtyards.

It is therefore a good idea to perform detailed studies of noise at locations where the engineering calculations are expected to be inaccurate. The studies may also be used for assessing the effects of noise reduction measures.

At TNO we are developing methods for performing such local studies of noise in cities. We think that the studies should be based on a combination of (advanced) computer models and *in situ* measurements. Our model-based measurement approach consists of three steps:

1) local measurement with various sensors (microphones, video cameras, …)
2) 'tuning' a suitable computer model to the local situation
3) application of the model

The measurement in step 1 typically takes one or a few days, during which all passing vehicles are registered by the sensors. In step 2, the recorded data are used to determine values of model parameters for the local situation ('tuning' of the model). Typical parameters that may be tuned are sound emission spectra of vehicles, effects of the road surface on the emission, and the sound absorbing and scattering properties of façades of buildings. In step 3, the 'tuned' model is applied to produce an accurate noise 'picture' of the situation, and effects of noise reduction measures may be calculated.

2 Measurements

As a step in the development of our model-based measurement technique we have performed measurements of traffic noise in a street in the city of Delft, The Netherlands. During a period of eight hours we recorded data of about 4000 passing vehicles, 1000 of which where found suitable for further analysis.

The experimental set-up consisted of five microphones (labelled 2-6; microphone 1 was not used for the analysis), two video cameras, and various sensors for determining the license numbers, driving speeds, and numbers of axles of the vehicles. Figure 1 shows a picture of the situation and figure 2 shows a schematic top view.

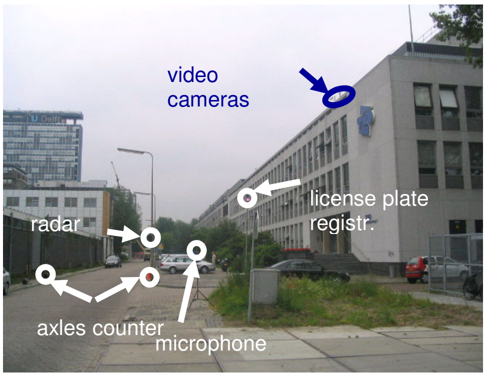

Fig. 1 Picture of the experimental set-up.

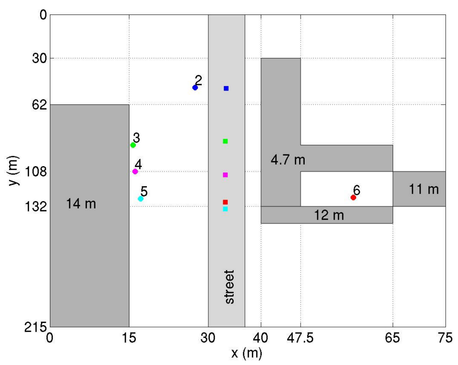

Fig. 2 Top view of the setup, with buildings (heights 14, 12, 11, 4.7 m), vehicle positions in the street (coloured squares), and microphones 2-6 (coloured circles).

The two cameras were used to determine the positions of the vehicles as a function of time. Microphone 2 was used for determining sound emission spectra of the vehicles. Sound from a passing vehicle reaches this microphone via a direct path and a reflection at the ground surface. A sound signal recorded at microphone 2 is easily converted into an emission spectrum. Microphones 3-5 were also used for determining sound emission spectra, but here the sound propagation is more complex, as reflections between the buildings along the street play a role here. Microphone 6 was located in a courtyard surrounded by buildings, so in this case we have sound propagation from one street canyon (the street) to another street canyon (the courtyard). Canyon-to-canyon propagation is a challenging problem for noise models, and we show in this paper that we need advanced numerical models to get accurate results for this case.

Figure 3 shows the variation of the A-weighted sound level during a period of 60 seconds, for the five microphones 2-6. The graph shows peaks due to passages of three vehicles, with lengths 14, 7, and 6 m. The vehicle of 14 m is a city bus, which is investigated in detail in this study. The + symbols in the graph indicate the 'optical' passage times as determined from the video data.

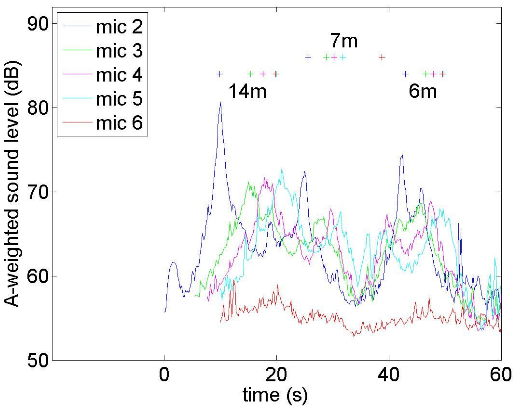

Fig. 3 A-weighted sound levels as a function of time, with three vehicles of length 14, 7, and 6 m. The vehicle of 14 m is the city bus investigated in detail in this study.

3 Comparison of experimental data with numerical model calculations

The analysis was restricted to the point where the sound level at a microphone is at its maximum, corresponding roughly to the point where the vehicle passes the microphone. The time signal in an interval of 0.2 s around the maximum was converted into a sound spectrum.

For a first analysis we assumed the Harmonoise emission model for road vehicles [1] and we calculated transmission loss spectra (excess attenuation spectra) with a ray model [2, 3]. The Harmonoise source model assumes two point sources at heights 0.01 m and 0.75 m for a vehicle such as a city bus. Since the road surface consisted of 'paving bricks' we applied an emission correction according to the Dutch calculation method (-5, 2, 3, 1, 1, -1, 1, -2 dB for frequency bands 63-8000 Hz, respectively). For the propagation we included sound rays with up to two facade reflections.

Figure 4 shows measured and calculated spectra of the city bus identified in figure 3, for microphones 2-6. For microphones 2-5 the agreement is better than for microphone 6. The differences for microphones 2-5 will be used as corrections to the Harmonoise emission model for this specific city bus. For example, the correction is about -5 dB for frequency band 250 Hz. In the remainder of this paper we will consider results for microphone 6.

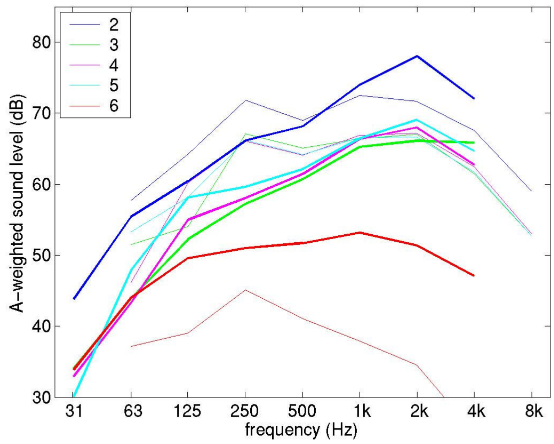

Fig. 4 Measured (thick lines) and calculated (thin lines) spectra of the A-weighted sound level, for microphones 2-6.

Figure 5 compares the measured spectrum for microphone 6 from figure 4 with spectra calculated with a BEM model (BEM = Boundary Element Method [4]) for four values of the energy reflection coefficient (R^2) of the façades of the buildings. For the calculations we assumed the Harmonoise emission model plus the road surface correction plus the emission correction from figure 4. The agreement in figure 5 is best for reflection coefficient 0.9, corresponding to an energy absorption coefficient of 0.1. Part of the absorption may be attributed to scattering at surface irregularities, since we assumed perfectly smooth façades with BEM.

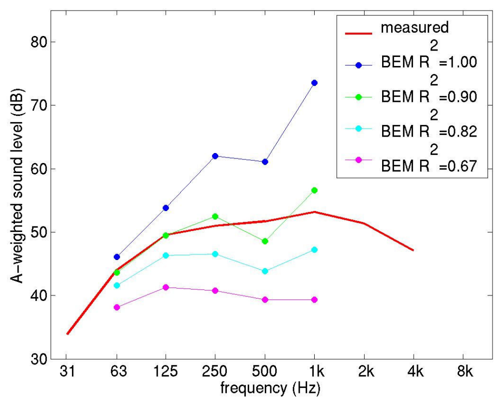

Fig. 5 Spectrum of the A-weighted sound level at microphone 6. BEM results are shown for four reflection coefficients, and the measured spectrum from figure 4 is shown.

The BEM model is based on numerical solution of the Kirchhoff-Helmholtz integral equation, *i.e.* the integral representation of the Helmholtz equation [5]. In this case we used a 2D BEM model, for the vertical plane through the source and the receiver. Implicitly, BEM takes into account all multiple facade reflections in the street canyons. We conclude that higher-order reflections in the street canyons play an important role, since the BEM result agrees with the measured spectrum, while the ray model result with up to two facade reflections does not (see figure 4).

We also compared the measured spectrum for microphone 6 with results of calculations with two other models: a time-domain model based on numerical integration of the linearized Euler equations [6], and a simple ray model taking into account higher-order reflections in street canyons [7]. Both models did not give results in agreement with the measurements.

4 Comparison of experimental data with scale model results

As an alternative approach we have also performed measurements on a 1:30 scale model of the situation with the city bus and microphone 6. The advantage of a scale model is that we can easily get results for complex geometries, taking into account 3D effects. The scale model measurements were performed in a semi-anechoic room, so reflections from the walls and the ceiling were eliminated. Figure 6 shows a picture of the experimental set-up.

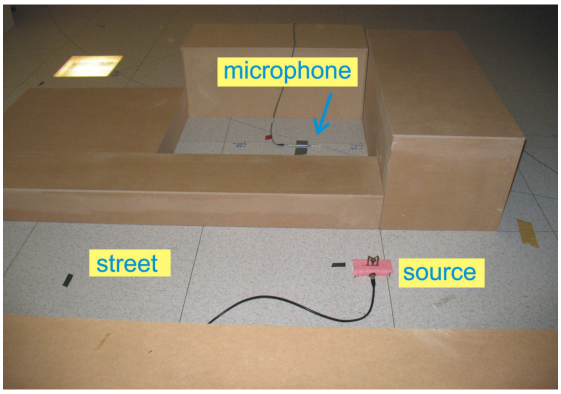

Fig. 6 Picture of the scale model.

We used a spark source to generate a short sound pulse. In this way we obtained a time signal at the microphone consisting of a series of sound pulses, corresponding to different sound paths with different numbers of facade reflections. Each pulse was converted to a spectrum, and corrected for atmospheric attenuation of high-frequency sound waves in the scale model. After scaling the frequencies with the scale factor of 30, we obtained a transmission loss spectrum. This spectrum was combined with the emission spectrum of the city bus to obtain the received spectrum at microphone 6. This spectrum is shown in figure 7, together with the measured spectrum, the BEM spectrum from figure 5, and a spectrum calculated with the Dutch calculation method (SRM) for road traffic noise [8], taking into account sound paths with zero or one facade reflection. The SRM model is similar to the international standard ISO 9613-2: Acoustics -- Attenuation of sound during propagation outdoors -- Part 2: General method of calculation. Broadband levels are indicated in the legend in figure 7.

For all calculations we used the Harmonoise source model, including the road surface correction and the emission correction from figure 4.

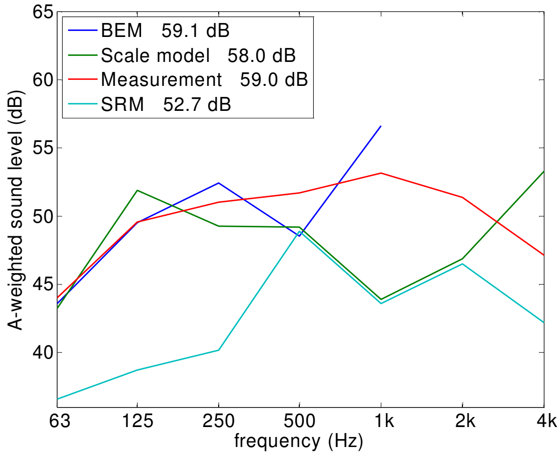

Fig. 7 BEM result, scale model result, experimental data and SRM result.

The scale model spectrum agrees with the measured spectrum up to frequency 500 Hz. At 1000 and 2000 Hz the scale model levels are too low. This can be partly attributed to the absorption of sound waves by the façades. In the scale model we used MDF plates, and we found that the absorption coefficient up to 500 Hz agrees roughly with the value of 0.1, while it is larger at higher frequency.

The spectrum calculated with the Dutch calculation method is considerably too low above 500 Hz. It should be noted that for other situations with street canyons we found even larger differences between SRM and BEM.

5 Conclusions

Standard engineering models are often inaccurate for prediction of traffic noise in cities, in particular in shielded areas such as courtyards. Multiple reflections in street canyons play an important role in urban traffic noise, and to model these reflections accurately one may use a BEM model. Other models such as a ray model and an engineering model were found to be less accurate. Noise levels in shielded areas depend sensitively on sound absorbing and scattering properties of façades of the buildings.

These conclusions have important implications for noise maps of cities calculated with standard engineering models. In particular in shielded areas, calculated noise levels may be considerably too low. Better accuracy can be achieved by performing calculations with more accurate models such as BEM, or by performing *in situ* analyses with a model-based measurement approach such as presented in this paper.

References

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