Loudness evaluation of road traffic noise abatement by tree belts

Timothy Van Renterghem1, Bert De Coensel2, and Dick Botteldooren3

1,2,3 Ghent University, Department of Information Technology, Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium

ABSTRACT
Detailed full-wave numerical calculations, partly based on measured input data, show that tree belts can be much more efficient than commonly thought. For road traffic noise applications, the trunks and the forest floor are expected to be responsible for the main part of the noise shielding. The choice of planting scheme and tree belt depth are essential parameters at realistic tree densities. The noise attenuation provided by a tree belt is discussed in relation to the one obtained by traditional thin rigid noise walls. The reference ground type between the edge of the road and the receiver showed to be an important parameter in this comparison. In case of rigid soil, a 30-m deep optimized tree belt could give a similar A-weighted sound pressure level as a 4-m high noise wall at receiver distances exceeding 50 m. For grass-covered ground, the equivalent noise screen height is typically lowered with roughly 1 m. Although both types of noise abatement change the frequency balance in a different way, the course of A-weighted sound pressure levels versus Zwicker loudness is rather similar.

Keywords: road traffic noise, tree belt, noise wall

1. INTRODUCTION
The application of tree belts along roads as a noise abatement solution is rather controversial. Measurements by Kragh [1] showed no useful effects, while Fang and Ling [2] showed that strong attenuation of noise by vegetation and tree belts is possible. Recently, detailed numerical calculations indicated that tree belts could indeed be effective in reducing road traffic noise, on condition that planting schemes are optimized and tree density is sufficiently high [3]. In addition, the calculations in [3] showed some useful approaches to limit the stem cover fraction, while only slightly lowering the noise reducing potential. The application of rectangular planting schemes, leaving gaps in between successive rows in the tree belt, and thinning are examples of such actions [3].

In addition, the use of tree belts as a noise reducing measure was shown to be robustly efficient in detailed benefit-cost analyses [4]. Major positive effects, besides noise reduction, are the low installation costs, the strong carbon sequestration potential, and the visual pleasantness. The benefit-cost ratio strongly depends on the land price [4].

The main physical effects leading to noise reduction by a tree belt are related to the soil and above-ground biomass. A forest floor is a highly porous medium, and most often covered with an acoustically soft plant litter layer. Compared to a (soft) outdoor soil like grassland, increased noise reduction is observed at low frequencies [5]. Multiple scattering in between tree trunks will redirect sound energy away from the direct line-of-sight between source and receiver. Although bark

1 timothy.van.renterghem@intec.ugent.be
2 bert.decoensel@intec.ugent.be
3 dick.botteldooren@intec.ugent.be
absorption is rather limited, there are many interactions, leading to noise reduction as well. Leaves were shown before to have an influence at high frequencies only (above 2 kHz), and are therefore of limited relevance in road traffic noise applications. In the current study, the predicted noise reduction by tree belts is opposed to a traditional noise abatement solution along motorways namely a vertical, straight noise wall. As noise walls reduce sound while relying on diffraction, strong effects are mainly observed at short distances only behind the wall and at high sound frequencies. The (relative) low frequency content in the noise spectrum increases which could lead to a negative perception. Screen-induced refraction of sound by (down)wind strongly reduces the shielding efficiency of such non-streamlined objects, even at short distances behind the barrier [6][7]. Shallow noise berms [8] or rows of trees [9] could provide a solution here. In addition, noise walls are strong visual intruders in the landscape with related problems [10]. The analysis is performed both in terms of A-weighted sound pressure levels and loudness evaluation, as noise walls and tree belts affect the noise spectrum in a different way.

2. CALCULATION METHODOLOGY AND PARAMETERS

2.1 Numerical methods

The calculations in this study are based on full-wave numerical methods, specifically the finite-difference time-domain method (FDTD) and the Green’s function Parabolic Equation method (GFPE). FDTD has been used to simulate the multiple scattering process in between the (partly absorbing) tree trunks, while GFPE was used to calculate the soil effect, including impedance discontinuities along the propagation path, and the presence of (rigid) noise walls.

2.2 Combining sound propagation in two cross-sections

Modeling the effect of a tree belt along a road is a full-3D sound propagation problem, while at the same time, a large area must be covered, including high frequencies. Therefore, the efficient approach as developed before in [11] has been used. Sound propagation in two orthogonal planes is modeled. This means that multiple scattering in between the trunks and the sound-soil interactions are treated separately. There is sufficient evidence that these effects do not interact and may be simply added to find its total effect [3].

2.3 Highway setup

A 4-lane road is considered, with 3.5-m wide lanes (see Figure 1). The noise abatement (either border of the tree belt, or the noise wall) is located directly at the edge of the road. Point sources are positioned with a spacing of 10 m on each lane along the road length axis, and a total road segment of 400 m is considered. Receivers are located normal to the road, at distances between 20 m and 200 m. No receivers are located inside the tree belt. Two reference soils are considered beside the road, namely a rigid or grass-covered ground. In case a tree belt is modeled, part of the reference soil is replaced by a forest floor. The noise wall does not influence the soil properties. Tree belts of limited depth (15 m or 30 m) are considered.

2.4 Numerical parameters

The road surface is modeled as fully rigid; grassland and the forest floor are modeled using the Zwicker and Kosten phenomenological model and appropriate parameters based on large sets of in-situ measurements as reported in [12]. Bark absorption is set to 0.075 and treated as frequency-independent, which was shown to be an adequate simplification based on the measurements reported in [13].

FDTD calculations are performed up to the 1/3-octave band of 1.6 kHz. In a conservative approach, noise shielding at higher frequencies by multiple scattering in between the trees is assumed to behave similarly as the 1.6-kHz 1/3-octave band. Ground interactions and the effect of the noise wall are explicitly calculated up to the 1/3-octave band of 5 kHz. Five frequencies for each 1/3-octave band were used.

Atmospheric absorption is included following ISO9613-1, by assuming an air temperature of 15°C, a relative humidity of 70 % and an ambient atmospheric pressure of 101325 Pa.

Following traffic parameters are used. The road (all lanes) carries 20 000 vehicles per 24 hours. The vehicle speed for both light and heavy vehicles (with a share of 25 %) is constant at 100 km/h. Traffic is freely flowing.
Figure 1 – Schematic overview (plan view) of the reference and abatements (tree belt and noise wall), in case of grass-covered and rigid soil beside the road.

2.5 Loudness assessment

The use of A-weighted equivalent levels for environmental noise annoyance assessment has been the subject of much research and debate over the past decades (see e.g. [14, 15]). Particularly, the limitations of A-weighting when considering environmental sound with strong low-frequency content, such as originating from heavy vehicle road traffic, are well known, and the use of loudness level weighting or loudness assessment is often suggested as a better alternative in these cases [16]. Therefore, in this work, loudness calculation according to ISO 532-B [17] is included, calculated based on the 1/3-octave band levels from the sound propagation calculations [18].

3. RESULTS AND DISCUSSION

The calculations show that tree belts can be a good alternative for noise walls. At very short distances, noise walls provide lower A-weighted sound pressure levels. However, the tree belts calculations are characterized by a steeper descent when the receiver is moved away from the road. Some of the tree belts considered here give more road traffic noise shielding than noise walls of 2 m in height.

Tree belts are especially interesting in case of rigid ground along the propagation path. The 30-m deep, dense tree belt approaches the same sound pressure levels as a 4-m high noise wall (see Figure 2). In case of less dense 30-m deep belts, the equivalent screen height is between 2 m and 3 m at all distances. Optimized 15-m deep belts have a similar performance as a 2-m high noise wall. In case of grassland as reference soil, this equivalent screen height is typically 1 m lower.

When analysing the dBA-loudness curves in case of grass-covered soil beside the road (see Figure 3), almost any curve coincides. There is a slightly lower loudness for noise walls above 45 dBA than for the tree belts. In case of a rigid reference ground (see Figure 4), the lower screen height gives a smaller loudness estimate for the same sound pressure level than higher screens. The higher screen curves are similar to those of the tree belts. Some small differences in loudness among the tree belts appear in the range 50-55 dBA. The reference case (sound propagation over open field) follows the low barrier curve as well.
Figure 2 – Sound pressure level (dBA) as a function of distance from the road edge for 15-m and 30-m deep tree belts, and noise walls with a height of 1 m, 2 m, 3 m and 4 m. The full gray line is the reference situation (sound propagation over rigid ground). Following coding has been used for the tree belts: “belt-depth normal to the road-diameter of the trunks-spacing along the road length axis, spacing normal to the road”. “R” indicates that small random shift are applied to the stem centre location; “M” means that 25% of the trees were (randomly) removed from the tree belt. The absence of “R” and “M” indicates fully regularly positioned, fully populated tree belts.

Figure 3 – Sound pressure level versus loudness for all cases and all distances modelled. See caption of Figure 2 for legend. The reference case is sound propagation over grassland.
Figure 4 – Sound pressure level versus loudness for all cases and distances modelled. See caption of Figure 2 for legend. The reference case is sound propagation over rigid ground.

4. CONCLUSIONS

Detailed sound propagation calculations comparing noise walls and tree belts positioned at the edge of a highway are performed. Tree belts showed to be a good alternative, both for the noise reduction and when taking into account the many additional non-acoustical advantages. In case of rigid soil in the reference case, a 30-m deep optimized tree belt could even give a similar A-weighted sound pressure level as a 4-m high rigid screen at distances exceeding 50 m from the road edge. The equivalent noise wall height is roughly 1 m lower in case of sound propagation over grassland. Somewhat surprisingly, noise walls and tree belts gave rather similar loudness-dBA curves, with even a slight preference for noise walls.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community’s Seventh Framework Program (FP7/2007–2013) under grant agreement no. 234306, collaborative project HOSANNA.

REFERENCES