A review of natural means for noise abatement

Keith ATTENBOROUGH

1 The Open University, UK

ABSTRACT

Natural means to reduce surface transport noise during propagation between source and receiver outdoors include tree belts, crops, earth berms and ‘soft’ ground effects. They can be exploited through landscaping and design. Although there are few full-scale demonstrations of what can be achieved, the noise reducing capabilities of the proposed arrangements have been tested in the laboratory and/or numerically evaluated. Well-designed, natural arrangements offer ways of abating surface transport noise, either to complement conventional noise barriers or provide useful alternatives in cases where noise barriers are neither practical nor desirable. While meteorological effects, such as downward refraction and turbulence, reduce the efficiency of usual methods of outdoor noise mitigation, judicious arrangements of vegetation and landscaping can counteract these effects as well as provide non-auditory benefits.

Keywords: Outdoor Sound, Ground effect, Attenuation

1. INTRODUCTION

A comparative study of noise levels in eight UK and six EU cities (1) has shown that overall noise levels depend on the proportions and distributions of green areas and porous ground. Sound levels tend to be higher in UK cities with higher building densities fewer green areas within 30 km² of the city centre. The balance and dispersion between green space surfaces and built-up surfaces turns out to be a more meaningful indicator than green space coverage alone. Noise levels will tend to be lower if more areas involve naturally porous ground since this will mean, in turn, that housing developments and road networks have lower densities and there will be larger distances between noise sources and dwellings. The usual decrease of noise levels with distance can be augmented by extra reductions from ‘soft’ ground effects, tree belts, crops, bushes and hedges. While acknowledging that there is growing evidence that ‘greening’ the environment has a positive influence on noise perception (2), this paper reviews measured and predicted noise reductions from certain types of ‘greening’, the physical mechanisms that contribute to these reductions, and ways in which they might be exploited.

2. GROUND EFFECTS

2.1 Porous ground

When the sound source is located above a ground surface, sound waves reflected from the ground combine with those travelling directly from the source. If the sound waves arriving along the two paths are in phase which is true at some frequencies whatever the surface, there are increased levels. When they are out of phase, at other frequencies, the total sound is less. These interactions are known as ground effect. Complicating factors such as multiple sources including engine and exhaust in the case of road traffic, atmospheric turbulence and naturally uneven and non-uniform ground mean that the increases in level due to acoustically-hard ground corresponds more nearly to energy doubling. If the ground is porous then not only is the magnitude of sound reduced on reflection but the phase change due to the finite (complex) ground impedance combines with the phase change due to path length difference with the consequence that, for a given source-receiver geometry, the first destructive interference occurs at a lower frequency than over hard ground. The resulting reduction in sound levels, sometimes called ‘ground absorption’, is important for surface transport noise. It depends on the type of ground surface and the locations of the sources and receivers.

According to the common methodological framework for strategic noise mapping under the Environmental Noise Directive (2002/49/EC) (3), “the acoustic absorption properties of ground are mainly
linked to its porosity". While porosity is a factor, the acoustical properties of porous ground are affected most by the ease with which air can move in and out of the ground surface. This is indicated by the flow resistivity which represents the ratio of the applied pressure gradient to the induced steady volume flow rate of air through the surface of the ground. The porosity of naturally-occurring ground surfaces does not vary as much as their flow resistivity. If the ground surface has a high flow resistivity, it means that it is difficult for air to flow through the surface. This can result from very low or negligible surface porosity. Hot-rolled asphalt and non-porous concrete have near zero porosity and a very high flow resistivity whereas many forest floors and freshly-fallen snow have very much lower flow resistivity and a high porosity.

The Calculation of Road Traffic Noise (CRTN) scheme (4), used for assessing eligibility for sound insulation of dwellings near new or improved roads in the UK, includes an allowance for the extra reduction in levels "If the ground surface between the edge of the nearside carriageway of the road or road segment and the reception point is totally or partially of an absorbent nature, (e.g. grassland, cultivated fields or plantations)". The extra reduction depends on the mean height of the sound travelling from the road source to the locations of interest and distance travelled over soft ground. It is noted that "To avoid the difficulty of defining adequately the many other more absorbent types of ground cover, the correction shown ... is to be used for all predominantly absorbent surfaces. Thus the calculations will slightly underestimate attenuation effects, particularly where the intervening ground is intensively cultivated or planted." A similar correction and the same qualifying statement appear in Calculation of Railway Noise (CRN) (5).

For a mean path height of 1.5 m, CRTN and CRN predict ‘soft ground’ reductions of 4 dB and 1 dB respectively at 50 m from the nearest side of a road or railway. The lower reduction for railway noise is consistent with the fact that wheel/rail sources are at a height of 0.4 m on the tops of tracks above sleepers and ballast and so are higher than tyre/road sources (assumed to be 0.01 m high).

HARMONOISE and NORD2000 prediction schemes (6, 7) identify eight categories of ground for the purposes of predicting the extra sound attenuation associated with porous ground effect. Three of them refer to various types of grass-covered ground. The categories are used to specify an effective flow resistivity that, in turn, can be used to predict the corresponding ground effect using an impedance model. More accurate allowance can be made for a specific soft ground if its surface impedance is known. Deduction of ground impedance from complex pressure ratios gives impedance-model-independent information but it might not always be convenient to make such measurements. To date relatively few deductions of ground impedance from complex pressure ratio measurements have been reported. It is more common to deduce parameter values for impedance models by fitting short range level difference spectra using ‘template’ methods (8, 9). Subsequently these models and parameter values can be employed in prediction schemes.

A one parameter semi-empirical model, used widely for outdoor sound prediction, is unphysical (10). For example, at low frequencies it predicts negative real parts of surface impedance and complex density. Comparisons of predictions with data obtained using signals from a point source at vertically separated microphones, have shown that, for many grasslands, physically admissible two parameter models lead to better agreement (11).

Although prediction schemes allow for ground effect, they are concerned with accounting for the existing environment rather than ways of exploiting ground effects for noise control. CRN includes an additional reduction of 1.5 dB as a result of the porous (sound absorbing) nature of ballast. For the same reason the use of porous rather than non-porous slab track is to be preferred when constructing high speed rail links. Porous road surfaces and road surfaces with embedded resonators are to be preferred to non-porous hot-rolled asphalt (12).

Measurements of the acoustical properties of ground surfaces together with numerical calculations of noise levels due to a 2-lane urban road (5% heavy vehicles, 95% light vehicles, travelling at 50 km/h), suggest a ‘soft’ ground reduction of 5 dB at a 1.5 m high receiver located 50 m from the road over compacted grassland. But for less compacted grassland (meadow) and the same receiver location, 8 dB reduction is predicted; significantly greater than the 4 dB predicted by CRTN for any grassland.

Predictions of urban road traffic noise spectra at 1.5 m high receiver 50 m from the road with intervening hard ground or either of two types of soft ground are compared in Fig. 1. The ‘softer’ ground is predicted to give 10 dB lower levels at peak traffic noise frequencies than the hard ground. Some predicted ‘ground cover’ reductions increase with distance faster than predicted by CRTN (13).

The introduction of grassy areas between and alongside tramways has been found to give perceptible noise reduction (12). Specifically, the introduction of grass between and alongside the tracks reduced tram noise levels at a 1.5 m high receiver 4 m from the nearest track by between 1 and 10 dB(A) with an average reduction of 3 dB(A). Moreover, a survey of subjective reactions suggested that the associated reduction in annoyance is equivalent to a further 1 - 2 dB reduction (see Fig.2).
2.2 Rough ground

If ground is otherwise acoustically hard, roughness, even at scales smaller than the shortest incident wavelength, affects outdoor sound propagation. The presence of small-scale roughness makes a surface that is acoustically hard at normal incidence appear acoustically soft near grazing incidence. Part of the incident sound energy is reflected in the specular direction and the remainder is scattered diffusely. The distribution of scattered sound depends on roughness topology, roughness dimensions compared to the incident wavelength, and the relative locations of source and receiver. If a sufficiently large fraction of the reflected sound retains a phase relationship with the incident sound so there is significant coherent scattering and specular reflection, there can be a significant roughness induced change in ground effect near grazing incidence. One method of deliberately introducing roughness outdoors is to construct an array of low parallel walls. Low walls with heights of 0.3 m or less (0.3 m is approximately the wavelength of sound in air at 1 kHz), can be considered as a form of artificially arranged ground roughness. The potential usefulness of regularly spaced low parallel walls for road traffic noise reduction was suggested and demonstrated in 1982 (14). An array of sixteen 0.21 m high parallel brick walls with edge-to-edge spacings of about 20 cm placed on compacted grassland was found to give a broadband (between 100 Hz and 12,500 Hz) insertion loss (IL) of slightly more than 4 dB(A) including insertion losses of up to 20 dB(A) in the 1/3 octave bands between 400 and 1000 Hz. The creation and subsequent attenuation of surface waves was considered as the main mechanism for noise reduction. Although surface wave creation is one of the consequences of placing a low parallel wall array on an acoustically hard ground, the array has a significant influence on ground
effect over a wider range of frequencies than those affected by the surface wave. This is demonstrated by the results of drive-by tests conducted with the brick configurations shown in Figure 3. Figure 4 shows spectra measured at a 1.5 m high receiver 10 m from the nearside wheels of car 1 and car 2 without and with the low parallel wall or lattice configurations respectively. The overall broadband insertion loss of about 3 dB due to a 2.30 m wide, 0.2 m high, 16 m long nine parallel wall array was found to be more or less the same as that of the 1.1 m wide square cell lattice wall configuration of the same height even though the latter occupies significantly less land area.

Figure 3 Parallel low wall and lattice brick arrangements used in drive-by tests

Figure 4 1/3 octave band SPL spectra measured by a 1.5 m high receiver 10 m from the nearside wheels of cars at their closest point of approach without and with the 2.30 m wide array of nine parallel brick walls using car 1 and a 1.1 m wide brick lattice using car 2 (15).

In contrast to the insertion loss due to 'soft' ground, the insertion losses predicted for the lattice and parallel wall configurations are not much affected if the receiver height is increased from 1.5 m to 4 m. This is a consequence of the predicted insertion loss 'beam' shown in Figure 5 which is a contour plot of overall insertion loss for a frequency range 178 Hz to 4.44 kHz due to a 0.2 m high 6 m wide lattice with 0.065 m thick walls and centre-to-centre spacing of 0.26 m with the nearside 2.5 m from a 0.05 m high line source emitting a spectrum corresponding to 70 km/h light vehicular traffic.

Figure 5 A plot of overall BEM predicted insertion loss contours from a 0.05 m high line source emitting a spectrum corresponding to light vehicles travelling at 70 km/h due to a 0.2 m high 6 m wide lattice.
A 'beam' of higher insertion loss (~6 dB) compared with hard smooth ground extends from 0.2 m near the source to about 5 m height at 100 m. The slightly lower insertion loss (~5 dB) predicted near the ground is a consequence of the roughness-induced surface wave.

3. NOISE REDUCTION BY CROPS, HEDGES AND TREE BELTS

3.1 Influence of vegetation on ground impedance
Growing plants create root zones and, thereby, change the near-surface flow resistivity and porosity. In the presence of plants, the ground surface has a different surface impedance to that for the same ground with little or no vegetation. The best fit impedance model parameters obtained from short range vertical level difference measurements over ground containing winter wheat crops (16) are an effective flow resistivity of 170 kPa s m\(^{-2}\) and a porosity of 0.2 using a two-parameter slit pore model (11). These values can be compared with those obtained over nearby bare ground, i.e. the same type of soil but on which no crops were growing or had been grown. In comparison, the best fit flow resistivity and porosity values over the bare unplanted ground are 2000 kPa s m\(^{-2}\) and 0.2 respectively which suggests that growing winter wheat reduced the effective flow resistivity of a soil surface by at least a factor of 10.

3.2 Visco-thermal losses in foliage
Foliage and stems in vegetation scatter sound and sound energy is converted into heat by viscous and thermal processes at leaf surfaces. In hedges and bushes there will be scattering by trunks and branches also. As a result of measuring sound transmission loss through dense corn, hemlock, red pine trees, hardwood brush and densely planted reeds in water, Aylor (17) suggested a relationship between normalised excess attenuation, i.e. the attenuation in excess of that due to ground effect divided by the square root of the product of foliage area per unit volume, \(F\), and path length, \(L\), and the scattering parameter (the product of wave-number, \(k\), and a characteristic leaf dimension, \(a\)). Figure 6 compares Aylor’s data for normalized excess attenuation through corn and reeds with predictions of eqn (1).

\[
\frac{EA(dB)}{\sqrt{FL}} = \frac{\sqrt{ka}}{(0.146 \frac{\sqrt{ka}}{ka}) + 0.76}
\]  

Figure 6 Aylor’s data for the normalized sound attenuation through corn (boxes \(F = 3/m\); diamonds \(F = 6.3/m\) with mean leaf width 0.074 m and reeds (open circles) with mean leaf width 0.032 m compared with predictions of equation (1) [solid line].

3.3 Propagation through crops
Measurements of sound transmission through winter wheat crops (average stem diameter 2.63 mm) have been compared with predictions including ground effect based on short range fitting of level difference spectra, multiple scattering by stems with known distribution of diameters, loss of coherence due to scattering and foliage attenuation by known leaf size and area density (16). Figures 7 compares spectra of the difference in levels at 0.3 m high receivers 1 m and at (a) 2.5 m (b) 7.5 m and (c) 10 m from a 0.3 m high loudspeaker source (continuous lines), and calculations of (i) ground effect alone (broken lines), using the 2-parameter slit pore model (flow resistivity 100 kPa s m\(^{-2}\) and
porosity 0.27), (ii) ground effect plus multiple scattering, and loss of coherence due to scattering using equivalent turbulence (18), and (iii) these effects plus visco-thermal attenuation in foliage. The total of the predicted effects agrees well with the data. A simpler way of predicting propagation over or through crops is to add ground effect and foliage effect only. This requires larger ‘effective’ values for foliage per unit area and mean leaf size but avoids the need for the detailed calculations of multiple scattering and of the loss of coherence (16).

Figure 7 Spectrum of the level difference between 0.3 m high reference receivers at 1 m and 10 m from a 0.3 m high omnidirectional source measured in 0.45 m to 0.5 m high winter wheat (solid [blue] line). Also shown (16) are predictions of ground effect alone (broken [red] line); ground effect plus incoherence plus multiple scattering by stems (broken [black] line); ground effect plus incoherence plus multiple scattering by stems plus visco-thermal attenuation (solid [black] line).

3.4 Propagation through hedges

Predictions of the simplified method have been compared also with data for transmission of sound from different single vehicles passing by a 2 m thick hornbeam hedge near a tennis court (19). Figure 7 compares predictions with data during pass-bys with two different vehicles. Overall pass-by experiments at two hedges gave median insertion loss values of between 1.5 and 3.6 dB(A).

Figure 8 (a) and (b) Sound level spectra measured during different car pass-bys without (continuous black lines) and with (broken blue lines) a 2 m thick hornbeam hedge and predictions (broken red lines) which sum the attenuations due to ground and foliage effects (19).

3.5 Propagation through trees

An important contribution to sound attenuation through a belt of trees is the destructive interference from ‘soft’ ground effect associated with the leaf litter and humus layers that form beneath the trees. This is reduced by scattering from tree trunks but supplemented at high frequencies by foliage attenuation. Figure 9 compares third octave band excess attenuation spectra (joined circles), obtained from measurements in a pine forest with an 0.8 m high loudspeaker source and 1.2 m high receivers at 10 m and 80 m respectively from the source in a pine forest, with predictions (broken lines) obtained by summing ground effect modified by scattering-induced incoherence and foliage attenuation (18). An analytical 3D scattering model for propagation in forests has been developed (20) which includes tree height as a parameter. But further work is needed to improve the ‘absorption cross section’ used to account for visco-thermal effects in foliage. Also, since the 3D scattering theory assumes random spacing, it does not account for the predicted potential additional attenuation resulting from regular spacing i.e. ‘sonic crystal’ effects (12).
4. MITIGATION OF ADVERSE METEOROLOGICAL EFFECTS

4.1 Downwind performance of noise barriers

A significant problem for conventional noise barriers outdoors is their interaction with meteorological conditions. The presence of the barrier disturbs the airflow during wind. The altered wind profile in the vicinity of a barrier causes deterioration in acoustical performance, since wind speed gradients and intensity of turbulence become larger near the barrier. The consequent increased refraction of sound during downwind sound propagation (sometimes called REfraction of Sound by WIND-induced Gradients (RESWING)), reduces the shadow region behind a barrier. As well as the additional refraction near the barrier, turbulence, including screen-induced turbulence, results in increased noise levels behind the barrier. But for thin rectangular barriers, broadband traffic noise and limited distances behind the noise barrier, turbulence effects are small compared with screen-induced refraction.

The effect of a row of trees (in leaf) behind a noise barrier, i.e. on the receiver side, on wind-gradient-induced refraction has been investigated. Measurements made continuously at a location with and without a row of trees behind a noise barrier from the middle of the summer until fall have been compared. For downwind locations and for an orthogonal incident wind, the efficiency of the noise barrier with trees was better than that of the noise barrier without trees and the downwind improvement increases with increasing wind speed (21).

4.2 Berms v barriers

Predictions indicate that roughening an acoustically hard berm can improve its insertion loss (12). Vegetated berms retain the soft ground effect that might be lost with the erection of a conventional barrier. Whereas the shielding by a conventional noise barrier can almost disappear for receivers downwind, predictions indicate that the insertion loss provided by a berm or bund of similar height can remain relatively unaffected (22). Where land use permits, in considering long-term equivalent noise levels, including periods with wind, acoustically soft and shallow berms are to be preferred to vertical barriers, since not only do they mitigate downwind effects and reduce potential nuisance caused by source side reflections, they offer non-acoustical, i.e. aesthetic, benefits.

5. CONCLUSIONS

Other ‘natural’ means for reducing noise include vegetative coverings on the faces of noise barriers and buildings and barriers made from cage-supported piles of stones (gabions). While it is difficult to use natural means to achieve reductions comparable say with a 2 m high conventional noise barrier, vegetation in urban spaces can contribute ‘positive’ sounds as well as reduce undesirable ones. Tree belts increase wind sounds and form corridors that attract animals and their associated calls. Vegetation on façades can improve the visual quality of environments. The extent to which such visual changes also influence auditory perception of noise is debatable. Nevertheless, the effect on the overall environment is important, and noise-mitigation methods that also improve aesthetic aspects are obviously better than methods that do not.

The HOSANNA project (12) looked also into the costs and benefits of the various methods for noise reduction. The most robustly cost-efficient of the environmentally friendly methods, after accounting for non-acoustical benefits such as air pollution reduction and bio-fuel generation, was...
found to be the provision of dense tree belts alongside surface transport corridors.

More work is needed to find optimum combinations of soil, vegetation and landscape. Only a start has been made in modelling, and, thereby, designing natural means of noise reduction. Exploration of these possibilities needs more accurate modelling than achievable with current prediction schemes (23). In any case, the use of non-physical models for describing acoustical properties of soils (6,7,24,25) should be avoided. Physically admissible models give at least as good predictions (10,11).

REFERENCES


2. Van Renterghem T. Towards explaining the positive effect of vegetation on the perception of environmental noise, Urban Forestry & Urban Greening, 2018, doi.org/10.1016/j.ufug.2018.03.007.


4. Department of Transport, Calculation of Road Traffic Noise, The Stationary Office, 1993,


8. ANSI/ASA S1.18-2018 American National Standard Method for Determining the Acoustic Impedance of Ground Surfaces (revision of S1.18-2010)


20. Ostashev et al, Sound Propagation in a Forest Based on 3D Multiple Scattering Theories ICA2019


