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Reduction of surface transport noise by ground roughness

I. Bashir [a], T. Hill [b], S. Taherzadeh [a,*], K. Attenborough [a], M. Hornikx [c]

[a] *Engineering and Innovation, The Open University, Milton Keynes MK7 6AA, UK*
[b] *Sonatest Ltd, Dickens Rd, Milton Keynes MK12 5QQ, UK*
[c] *Technische Universiteit Eindhoven, Eindhoven, Netherlands*

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ABSTRACT

Measured insertion losses due to the ground effects associated with low configurations of loosely stacked household bricks on a car park are reported. A particularly successful design has the form of a two brick high square lattice which is found to offer a similar insertion loss to regularly-spaced parallel wall arrays of the same height but twice the total width. Part of the insertion loss due to the roughness configurations is the result of transfer of incident sound energy to surface waves which can be reduced by introducing wall absorption or material absorption in the form, for example, of shallow gravel layer. Predicted finite length effects have been explored using a Pseudo-Spectral Time Domain Method, which models the complete 3D roughness profile. It is concluded from measurements and predictions that the lattice design has less dependence on azimuthal source-receiver angle than parallel wall configurations. These predictions are supported by measurements of level difference spectra as a function of azimuthal angle. A 2D Boundary Element Method gives predictions that agree well with data for parallel wall arrays up to 16 m long and it is used to investigate the potential insertion loss of longer configurations up to 0.3 m high. It has been found possible also to make predictions of the insertion loss due to infinitely long 3D lattices using the 2D BEM with the lattice represented by the surface impedance derived from fitting short range data with a slit-pore impedance model. The insertion losses of recessed configurations are predicted to be approximately 3 dB less than those of embossed configurations of the same size. Outdoor experiments also show that pathways can be made through such roughness configurations without significantly affecting their insertion loss. It is concluded that artificial roughness configurations could achieve substantial noise reduction along surface transport corridors without breaking line of sight between source and receiver, thereby proving useful alternatives to noise barriers.

1. Introduction

Noise barriers are a traditional method of reducing traffic noise. These obstruct the direct path between the source and the receiver thereby causing the sound to diffract over the top of the barrier. The performance of noise barriers depends on the inverse ratio of incident sound wavelength to the difference between the lengths of the direct path between source and receiver and that from source and receiver via the top of the barrier. The greater this ratio, the greater is the attenuation. To be most effective a barrier should be placed as close as possible to source or receiver. If the barrier is positioned close to the source, its effectiveness decreases as the receiver moves further way. The acoustical benefits afforded by noise barriers have to be compared with the facts that they obscure the line of sight between source and receiver, have a significant visual impact, divide communities and interfere with wildlife corridors. Gaps in a noise barrier reduce its effectiveness and the presence of a barrier reduces any pre-existing ground effect by increasing the mean path height to the receiver.

Ground effect includes destructive and constructive interference between direct and ground-reflected sound and leads to a frequency-dependent attenuation in excess of that due to wavefront spreading and atmospheric absorption [1]. Even the category of ground known as 'grassland' involves a wide range of ground effects [2,3]. Hitherto recognition that ground effects may contribute to traffic noise attenuation, have been restricted to outdoor surfaces that are porous. Deliberate exploitation of ground effects has been restricted to the development of porous road surfaces which inhibit traffic noise generation as well as propagation. Less attention has been paid to exploitation of the finite impedance induced by the presence of roughness on an otherwise acoustically-hard ground. This is the result of multiple scattering by roughness elements [2,4].

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* Corresponding author. Tel.: +44 1908653320.
E-mail address: shahram.taherzadeh@open.ac.uk (S. Taherzadeh).

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The potential usefulness of regularly-spaced low parallel walls for road traffic noise reduction was suggested and demonstrated by outdoor experiments in 1982 [5]. An array of sixteen 0.21 m high parallel brick walls with edge-to-edge spacings of about 20 cm 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 acoustical effects of a low parallel wall array placed on an acoustically-hard ground, as discussed later, the array has a significant influence on ground effect over a wider range of frequencies than those affected directly by the surface wave generation.

Bougdah et al. [6] reported laboratory measurements over arrays of up to 17 thin walls with (equal) heights and spacing between 8 cm and 25 cm. They measured a maximum overall insertion loss of 10.3 dB for a 3.25 m wide 14-wall array with height and spacing of 0.25 m with the wall nearest the source located at the specular reflection point halfway between source and receiver which were at 0.4 m height and separated by 10 m. They discussed three physical effects other than surface wave creation and the effective ground impedance that may be involved. One of these is quarter wave resonance. In an array of identical 0.3 m high walls, this resonance would occur at 283 Hz. Predictions and data discussed later show that this mechanism is not important. They refer also to diffraction-grating effects. Essentially these are related to the diffraction-assisted ground effect, which has been explored subsequently in more detail [7]. The third additional mechanism they suggest is that of interference between direct and multiply-reflected (between adjacent walls) paths. But this mechanism should be regarded as part of diffraction assisted ground effect rather than as a separate phenomenon. More extensive laboratory measurements have shown that excess attenuation spectra are influenced by the number and spacing of roughness elements and by their profile or shape [7]. The influence is not investigated in Bougdah et al. [6] since only identical rectangular, thin acoustically-hard rib-like elements (vertical strips) were considered.

As well as being porous, most naturally-occurring outdoor ground surfaces are rough at some scale. Surface roughness scatters the sound both coherently and incoherently. The relative strengths of the coherent and incoherent parts of the scattered energy depend on the mean size of the roughness compared with the incident wavelength. An important conclusion of previous work with regard to the coherent part of the scattering from the surface is that, effectively, the impedance (or its inverse, the admittance) of the boundary is modified by the presence of small-scale roughness. Clearly this can be considered to have an influence on the (spherical-wave) reflection coefficient and hence on the ground effect, particularly near grazing incidence, even above a surface that would have been considered acoustically-hard when smooth. Once the roughness height approaches or exceeds the wavelengths of interest, non-specular (incoherent) scattering dominates and interference effects are destroyed. When the roughness elements are sufficiently tall compared with the wavelength they act as multiple noise barriers.

Tolstoy [8] has distinguished between two approaches for predicting the *coherent* field resulting from boundary roughness when the typical roughness height is small compared to a wavelength. These are the *stochastic* and the *boss* models. Both of these reduce the rough surface scattering problem to the use of a suitable boundary condition at a *smoothed* boundary. According to Tolstoy [8], the *boss* method, originally derived by Biot [9] and Twersky [10], has the advantages that (i) it is more accurate to first order, (ii) it may be used even in conditions where the roughness shapes introduce steep slopes and (iii) it is reasonably accurate even when the roughness size approaches a wavelength. Another advantage of the 'boss' approach to modelling roughness effects in outdoor sound calculations is that it may be used to predict propagation over artificially created rough surfaces both for experimental validation of theory and for designing useful roughness-induced ground effect over hard surfaces. Tolstoy considered sound propagation at the rough interface between two fluids [11]. His results have been used to predict the effective impedance of a rough impedance boundary [12,13].

Laboratory and outdoor measurements have shown that acoustically-hard surfaces containing roughness elements with heights and spacing less than the shortest wavelength of interest (say 0.17 m corresponding to 2 kHz), produce a frequency-dependent excess attenuation at much lower frequencies than would be the case for smooth hard ground [7,12–17]. For source-receiver geometries, and in particular the tyre/road noise source, the first destructive interference due to the presence of a smooth hard ground would be at too high a frequency to contribute to a perceptible attenuation of noise. However the deliberate introduction of roughness can cause the first destructive interference to be at a significantly lower frequency. This suggests that a potential passive method of noise reduction is to exploit the acoustical properties of roughened hard ground surfaces between the road and listeners. This should be visually less intrusive than, for example, erecting noise barriers. This paper reports work that investigates this idea.

Section 2 reports on experiments using arrays of parallel brick walls and brick lattices of 0.2 m or 0.3 m height. Insertion losses have been measured using a loudspeaker source, during distant road traffic noise events and during drive by tests. It is shown that the Boundary Element Method can be used to predict the results of measurements on low parallel walls. Level difference spectra obtained with both source and vertically-separated receivers above brick lattices are used to deduce their effective impedance spectra. For source and receiver outside the brick lattice, it is shown that BEM predictions over a raised impedance surface corresponding to the lattice fit relevant excess attenuation data. Section 3 presents numerical predictions of azimuthal source-receiver angle and finite length effects. In Section 4, the BEM method is used to predict the likely insertion losses for road traffic noise sources due to parallel wall and lattice arrays including various height profiles. Section 5 offers concluding remarks.

2. Experiments with brick arrays

2.1. Measurements on distant traffic noise

Investigations of the acoustical performance of roughness arrays on asphalt-covered car parks have been performed using both a loudspeaker source and vehicle noise. Initially a nine-wall array was constructed on a car park at the south-west corner of the Open University campus. The bricks were stacked with 'frogs' facing towards a busy main road, which was approximately 135 m away and elevated by approximately 5 m above the car park. Measurements were carried out by placing Microphone 1 (reference) in front of the walls and Microphone 2 behind the walls as shown in Fig. 1(b). Also the bricks were rearranged into a 'staggered 3D' pattern by displacing alternate pairs of bricks in the parallel walls to the midpoint between the original walls and measurements of traffic noise were repeated. The resulting array had the same 'roughness' volume per unit area as the parallel wall arrangement. Fig. 1(a and b) shows the brick patterns and example microphone locations. Fig. 1(a) also shows the loudspeaker and loudspeaker position for measurements described later in this section. Table 1 summarizes the array configurations, microphones heights and positions and corresponding insertion loss measured due to