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Meteorological effects on the noise reducing performance of a low parallel wall structure

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ABSTRACT

Numerical calculations, scale model experiments and real-life implementations have shown that the insertion of a closely spaced array of low parallel walls of finite dimension beside a road is potentially useful for road traffic noise abatement. However, previous studies did not consider atmospheric effects. In this work, numerical techniques have been used to predict the sound reduction provided by a low parallel wall structure, subject to wind and temperature related atmospheric effects. Three full-wave prediction schemes show very good agreement when looking at the insertion loss of a low 6 m wide parallel wall structure, consisting of 24 regularly spaced 0.2-m high rigid walls. Meteorological effects are predicted not to deteriorate the insertion loss (relative to rigid flat ground) of the parallel wall array in the low frequency range. However, at high sound frequencies the insertion loss is strongly reduced by downward refraction at a distance of 50 m in case of strong wind. Consequently, overall A-weighted road traffic noise insertion loss will be significantly lower during wind episodes. Although weak turbulence does not alter the energy time-averaged insertion losses, strong turbulence reduces the noise shielding in the high frequency range also. As with conventional noise walls, when considering use of low parallel wall structures for noise reduction outdoors, even at short distances, atmospheric effects should be considered.

1. Introduction

Road traffic noise abatement by low parallel walls (LPWs), also called "parallel grooves" or "comblike" or "riblike" structures, can be tracked back to 1982 [1] (when only considering peer-reviewed journal papers). More recently, there has been a renewed interest in LPWs [2–5]. The advantages of such structures for noise abatement are the preservation of the openness of the landscape near the road (in strong contrast to the traditional noise wall), the fact that paths can be made through them without compromising their acoustic performance and their potentially low cost.

Bougdah et al. [2] discussed possible phenomena when sound waves interact with a LPW structure. The cavities formed by the parallel walls could act as quarter-wave length resonators; sound waves passing over the tops of the walls are partly cancelled at specific sound frequencies by reflections coming from the bottoms of the cavities. When regularly spaced, the parallel wall structure can also be seen as a diffraction grating, leading to distinct zones with constructive and destructive interference depending on the angle of incidence and receiver angle. Thirdly, the diffracted waves at the wall edges and the (delayed) reflected sound waves in between the cavities may interfere. Multiple paths are possible inside the grooves, leading to complex interference effects extending over relatively large frequency intervals. Given that all these effects occur simultaneously, their relative importance with respect to noise reduction is difficult to establish. In addition, especially for rolling noise being generated at only a few centimeters above the road surface, diffraction at the (effective) impedance discontinuity occurs, further complicating physical explanation. In Ref. [6], the effects observed with such LPW structures are called diffraction-assisted ground effects.

An important aspect of the acoustical performance of LPWs is that surface waves [7–9] will be excited resulting in a redistribution of spectral energy in sound propagating over them. In contrast to the aforementioned effects, surface waves lead to amplification of sound in a narrow band of frequencies. Sound energy is trapped in a zone close to the surface [8], and the decay of sound intensity with distance becomes less pronounced [8]. Conditions for surface wave generation are met when, upon grazing incidence,

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the imaginary part of the equivalent surface impedance, by which such a LPW could be represented, exceeds its real part [1,2,10,8]. However, the surface waves can be mitigated by making the walls (partly) absorbing or by (partially) filling the space in between the walls with a porous medium such as gravel [3,9]. By doing so, a resistive part is added to the LPW's equivalent impedance which otherwise can be considered as purely reactive [7,1,2,9]. Other ways of reducing surface waves generated by LPWs are using a smaller number of walls [2] and introducing some randomness in the LPW structure [6].

The usefulness of parallel walls has been shown before by means of scale model studies [2,9,3], real-life implementations with artificial sound sources [1,3] and drive-by tests [3,5], and by numerical simulations [9,3]. So far, only the efficiency in a still and homogeneous atmosphere has been investigated.

Turbulence is known to strongly limit the magnitude of destructive interference dips that appear between direct sound and ground reflected sound outdoors [11,12]. Downward refraction of sound will lead to multiple sound paths arriving at a single receiver [11], and to changes in path length. Meteorological effects can be expected to affect the performance of LPWs at higher frequencies since LPWs are mainly related to interferences.

The main goal of this paper is to show the effect of refraction and turbulent scattering on the insertion loss of LPW structures by means of numerical predictions. Various techniques have been employed and the agreement between them might serve as a cross-validation of the predictions. A single (raised) LPW structure has been chosen for road traffic noise applications. Alternatively, sunken geometries [5,3] could have the benefit of allowing cars to drive over it when needed, meaning that a placement close to the traffic lanes (e.g. on the emergency lane or central reservation) is possible. However, such geometries perform slightly worse than the equivalent raised ones [3] in a non-refracting and non-turbulent atmosphere. The focus in this study is therefore on the latter.

This paper does not intend to provide a full parameter study of all parameters involved in LPWs, or simulating its performance in multi-lane road traffic noise cases. Such studies can be found elsewhere, see e.g. Refs. [9,3]. For simplicity, all surfaces are modelled as rigid, notwithstanding that this is known to promote surface waves. The interaction between atmospheric effects and individual LPW parameters like height, spacing, wall thickness etc. is not studied either.

2. Low parallel wall case

A source is positioned at (x, z) (0, 0.01) m, representative for the rolling noise source in road traffic [13,14], which is the dominant contribution in the direct vicinity of highways. Receivers are located at 50 m from the source, at heights of either 1.5 m (representing the average ear height of pedestrians) or 4 m (height of the first storey of buildings as commonly used in noise maps). All surfaces are rigid.

A regularly spaced LPW configuration was considered (see Figs. 1 and 2), containing 24 walls, all 0.2 m high and 0.065 m thick, starting at 2.5 m (i.e. the left face of the first wall) from the source, with a centre-to-centre spacing of 0.26 m. The right face of the last wall is positioned at 8.545 m from the source. The dimensions of the LPWs considered here are roughly based on household bricks placed on their sides; using such bricks could be a cheap way of constructing a LPW in practice. A minimum distance between the first wall and the source is needed for safety reasons.

3. Numerical techniques and parameters

3.1. Sound propagation models

Three numerical techniques have been used to assess the sound pressure level reduction provided by the LPWs, which are shortly described in the subsequent subsections. Discriminating features of the numerical techniques are the possibility to model wind and/or turbulence, whether calculations were performed in two dimensions or in 3D, and whether the effective sound speed approach [11,15] was used or the (full) Linearised Euler Equations (LEE) [16–18] were solved when modelling wind effects. The frequency range considered contains the 1/3 octave bands between 50 Hz and 2500 Hz.

3.1.1. BEM

The boundary element method (BEM) is a well-established technique solving the Helmholtz equation in the frequency domain. Simulations are here limited to sound propagation in a still and homogeneous atmosphere. Calculations were performed in 2D with explicitly modelled parallel walls using the code described in Ref. [6]. The method used 10 computational cells per wavelength and allows for exactly positioning discretisation points at the wall-air interfaces. Reflection from the underlying ground is included in the Green's function and therefore the ground was not discretised. This greatly reduces the computational effort. Six frequencies were calculated to constitute each 1/3 octave band.

3.1.2. FDTD

The pressure-velocity (P-V) staggered-in-place (SIP) staggered-in-time (SIT) finite-difference time-domain (FDTD) model [19] is used. When relying on the effective sound speed approach, accurate results can be obtained in the case of wind flowing parallel to flat ground [20], while keeping the computational cost significantly smaller than fully solving the LEE (see also Appendix B).

The spatial discretisation step was chosen to be 1 cm, sufficiently small for resolving the 2.5-kHz 1/3 octave band. The temporal discretisation was set to 20 μs, ensuring numerical stability, optimal computing speed and minimum phase error [21]. On the left, right and upper boundaries, perfectly matched layers [22] are placed to simulate continuation of the propagation region and thus zero-reflection calculation domain termination. The PML equations use the effective sound speed approach as well, by taking the effective sound speeds appearing closest to the inner region of the simulation domain [19].

The parallel walls were explicitly modelled with best fitting square cells, which comes at no additional (numerical) cost given

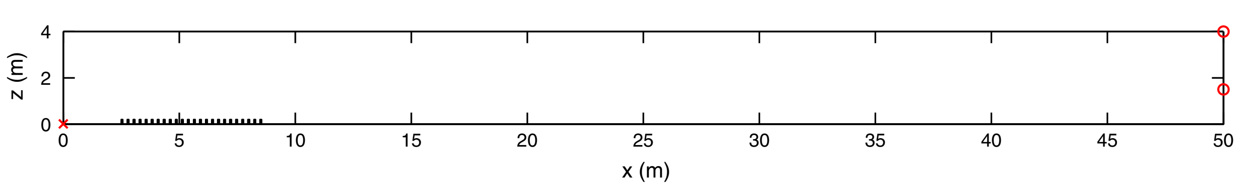

Fig. 1. Geometry studied, indicating the low parallel wall structure, the source (cross) and receivers (open circles).