inter-noise 83

GROUND EFFECT IN OUTDOOR NOISE PROPAGATION

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INTRODUCTION

Ground effect is particularly important at low frequencies. Above 500 Hz, ground effects tend to be swamped by those due to wind and/or temperature gradients [1]. On the other hand, below 250 Hz the attenuation of sound propagating outdoors near to a porous surface is determined mainly by the properties of that surface. It has become accepted that the acoustical properties of various ground surfaces can be characterised adequately by assuming each ground to be locally-reacting and by using an estimated flow resistivity σ mks units in an empirical relationship for relative characteristic impedance

$$Z = 1 + 0.061\ (f/\sigma)^{-0.75} + i\ 0.077\ (f/\sigma)^{-0.73} \qquad (1)$$

The appropriate value of σ is estimated by fitting propagation data using well-established expressions for the field due to a point source above an impedance boundary.

For the prediction of long-range low-frequency outdoor sound propagation over plane ground surfaces the empirical formula offers two possibilities:

(i) a short-range measurement at the site of interest could be used to find a best-fit impedance (flow resistivity) and this can then be used to predict long-range propagation or (ii) a measured flow resistivity could be used in equation [1] and thus enable prediction of long-range sound propagation.

A fundamental problem is that certain grass and non-grass surfaces have measured surface impedances that are not fitted well by the empirical formula using any value of flow resistivity.

Recent developments in the theory of the acoustical behaviour rigid-framed granular media [2] require knowledge of three parameters in addition to flow resistivity. These are porosity (Ω), grain shape factor and a pore shape factor ratio ($n/\sqrt{s}$). For soils, the grain shape factor is unity and comparison with limited data from direct measurements on soil surfaces suggests that it is reasonable to take the pore shape factor ratio equal to 0.75 [3]. On this basis it is possible to compare the predictions based on the low-frequency approximations of this theory with those based upon the empirical formula for long-range sound propagation over both plane homogeneous and inhomogeneous grounds.

PROPAGATION OVER HOMOGENEOUS GROUND

The empirical formulae were derived from measurements on fibrous absorbents with porosity near unity and $8{,}000 < \sigma < 80{,}000$ m.k.s. units approximately. Strictly their use for low porosity, high flow resistivity granular media should require use of $\Omega\sigma$ instead of σ [2]. The empirical formula for the propagation constant is

$$k_b/k = 1 + 0.978(f/\sigma)^{-0.693} + i\ 0.189(f/\sigma)^{-0.618} \qquad (2)$$

where k_o is the wave number in air.

The low frequency approximation of the rigid-framed granular theory [2] is independent of the grain shape factor and gives

$$k_b/k_o = Z = 1.37(n/\sqrt{s})\ (f/\Omega\sigma)^{-\frac{1}{2}}\ (1 + i) \qquad (3)$$

The empirical formula (2) suggests a higher frequency dependence than the theory and much higher attenuations particularly for typical pore shapes that depart form circular capillaries.

In Figure 1 are shown indirect measurements of the impedance of a sandy soil as deduced from the acoustic field along an inclined track between 6.54 m and 16.95 m horizontal separation from a loudspeaker source of continuous pure tones [4]. The measured value of σ of the soil was 366 000 ± 108 000. The chain curves shown in Figure 1 for comparison are the empirical predictions for $\sigma = 315000$ and $\sigma = 132500$ corresponding to best fit values and to mean measured σ multiplied by measured porosity (0.362) respectively. Also shown as solid lines are the predictions of the theory [2] for $\sigma = 366\ 000$. Although both the empirical formula (using best fit σ) and the theory [2] fit the impedance data equally well, the implied frequency dependences are rather different as are the relative magnitudes of real and imaginary parts of the impedance. Both the empirical formula and the theory [2] enable a good fit (within ± 2 dB at all frequencies) to the measured sound field at 17m horizontal source/receiver separation and for source and receiver heights of 1.83m. However, as shown in Figure 2, the predictions for the propagated field at 200 m horizontal separation and the same source and receiver heights are considerably different.

PROPAGATION OVER INHOMOGENEOUS GROUND

The empirical formula(1) gives a real part of Z (R) that is less than the imaginary part (X) at low frequencies with consequent reduction in the predicted excess attenuation at low frequencies and grazing-incidence over plane porous ground. Conversely, the theory [2] predicts that real and imaginary parts are approximately equal and that R is never less than X is the ground is homogeneous. Measured data shows both cases to be possible [5]. By using the low frequency approximations (3) and (4), to consider the effects of decrease of porosity with depth (and hence increasing σ). decreasing porosity with depth is most likely in virgin (uncultivated) land. Uniform porosity with depth is more typical of cultivated land.

structure which exhibits an extreme form of porosity variation with depth is that of layered ground. Obvious examples of this are the forest floor and snow [5]. If the ground structure is known to be of this type then use of a single flow resistivity and the empirical formula will be suspect. Even if the flow resistivities of the surface and underlying strata are known then the use of the empirical formulae is likely to give considerable errors in the predicition of impedance and hence of excess attenuation.

CONCLUDING REMARKS

Developments in the theory of acoustical properties of rigid-frame granular materials enable examination of circumstances in which use of the empirical formulae will give rise to errors. Furthermore these developments may enable a classification of ground surfaces according to physical (non-acoustic) properties from which acoustical performance may be predicted.

ACKNOWLEDGMENT

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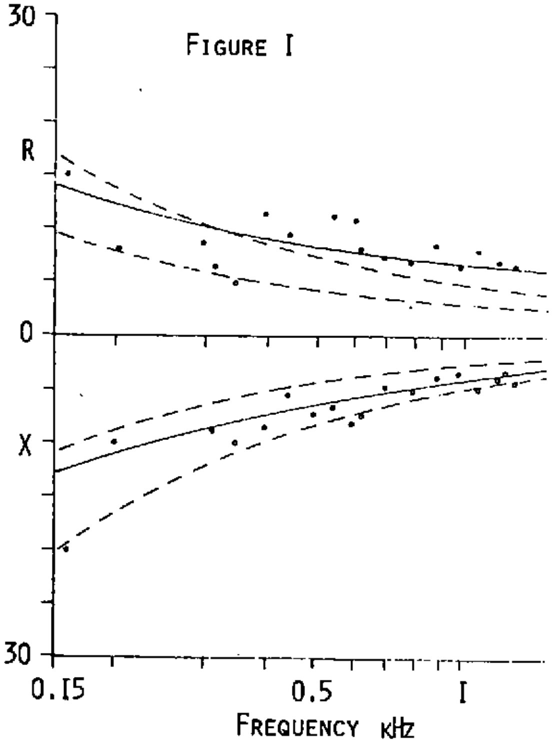

FIGURE I

(5) Attenborough, K.
Predicted ground effect for Highway Noise J.Sound Vib. 81(3) 4I3-424 (1983)

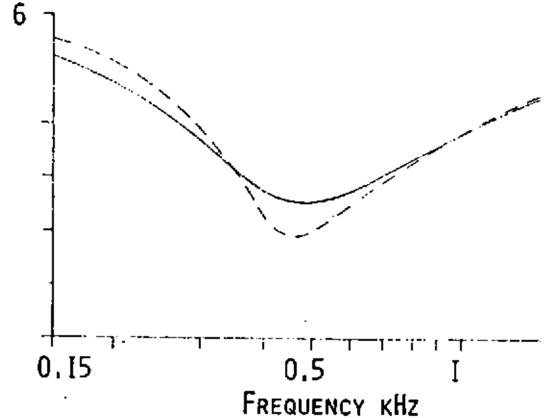

FIGURE 2

30. NOISE CONTROL ELEMENTS

31. Barriers and screens, shielding
32. Enclosures for noise sources
33. Seals for openings
34. Filters, mufflers, silencers and resonators
35. Absorptive materials
36. Ear protective devices
37. Noise attenuation in ducts
38. Special treatments