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MODELS AND MEASUREMENTS OF SOUND PROPAGATION FROM A POINT SOURCE OVER MIXED IMPEDANCE GROUND

P Boulanger, T Waters-Fuller, K Attenborough & K M LI

Faculty of Technology, The Open University, Milton Keynes, UK

INTRODUCTION

The propagation of sound above ground of mixed impedance is a subject of increasing interest for noise prediction and for exploitation of ground effect. There is a need for validation and comparison of models that enable prediction of excess attenuation spectra in the presence of ground planes containing single and multiple impedance discontinuities.

In this study, laboratory measurements of the excess attenuation of sound from a point source over mixed impedance ground in an anechoic chamber are compared with predictions obtained from four models. These models are based (a) on a semi-empirical modification of the equation for diffraction, (b) on solution of the Helmholtz equation obtained by using a Fourier transform technique, (c) on consideration of Fresnel-zone contributions and (d) a boundary element code. The possibilities of sound cancellation due to ground effect using either the percentage of hard ground cover or single/multiple discontinuity impedance ground as variables are investigated. Finally, we study the influence of the source heights and the proportion of hard ground cover on predicted A-weighted excess attenuation at long range.

THE DE JONG MODEL

This model has been developed by B.A. De Jong [1] and uses an approximation of diffraction theory at a semi-infinite wedge. The pressure above a plane containing a single impedance discontinuity is

$$\frac{P}{P_1} = 1 + \frac{R_1}{R_2} Q_{1,2} \exp\left\{ik\left(R_2 - R_1\right)\right\} + \left(Q_2 - Q_1\right)\frac{e^{\frac{-i\pi}{4}}}{\sqrt{\pi}}\frac{R_1}{R_3}\left\{F_{31} \pm F_{32}\exp\left\{ik\left(R_2 - R_1\right)\right\}\right\} \quad (1)$$

An explanation of the terms used in this equation can be found in Hothersall and Harriott's paper [2].
The impedance model used in the De Jong model and the other propagation models is based on an assumed log-normal distribution of triangular pores [3]. This impedance model has been simplified for the repetitive calculations necessary here by the use of Padé approximation techniques [4].
The empirical model developed by De Jong can be easily extended to multiple strips by summing over all the diffraction terms arising from each impedance discontinuity. This method was outlined by Bassiouni et all [5].

THE BOUNDARY ELEMENT MODEL

Chandler Wilde and Hothersall [6] have developed a method based on a boundary integral equation formulation to evaluate the pressure at the receiver. A solution for the Helmholtz equation for the pressure at the receiver can be solved for a locally reacting boundary and gives for the case of a strip with impedance Z_2 imbedded in a plane of impedance Z_1

$$P(\bar{r},\bar{r}_0)=P_1(\bar{r},\bar{r}_0)-ik\left(\frac{1}{Z_2}-\frac{1}{Z_1}\right)\int_s G_{Z_1}(\bar{r}_s,\bar{r})P(\bar{r}_s,\bar{r}_0)ds(\bar{r}_s) \qquad (2)$$

An explanation of the terms used in this equation can be found in Hothersall and Harriott's paper [2]. The integral can be calculated numerically by a standard boundary element technique once the pressure $P(\bar{r}_s,\bar{r}_0)$ is known at point $\bar{r}_s$ in the strip. An equivalent two-dimensional problem can be solved in order to save computation time. For the calculations presented here, source, receiver and specular point are in a vertical plane perpendicular to the impedance discontinuity, and thus, a line integral is solved instead of a surface integral.

THE FRESNEL-ZONE MODEL

The Fresnel-zone model assumes that the significant reflection occurs within the region around the specular reflection point defined by a Fresnel-zone condition. The method used in our work is improved compared to previous models [2] which assumed an excess attenuation dependent on the proportions of the different surfaces on the line representing the Fresnel-zone. In this work we assume that the excess attenuation is dependent on the proportion of the different surface areas inside the elliptical Fresnel-zone. A second improvement is the use of the following definition of the excess attenuation in mixed impedance cases:

$$EA=20\log\left\{\mu\left|1+\frac{R_1}{R_2}Q_1\exp ik(R_2-R_1)\right|+(1-\mu)\left|1+\frac{R_1}{R_2}Q_2\exp ik(R_2-R_1)\right|\right\} \quad (3)$$

where the coefficient μ is obtained by calculating the proportion of area having surface impedance Z_1 inside the elliptical Fresnel-zone. We note that the Fresnel-zone model can be easily applied to multiple strips.

NYBERG'S THEORY

Christer Nyberg [7] showed that if a point source has Cartesian coordinates $(0,0,z_0)$ above a flat surface with a specific acoustic admittance $\beta(y)$, the wave field ψ at the point R(x,y,z) can be found as the solution of a helmholtz equation and boundary condition. In the case of a two-valued infinite periodic striped impedance, if the term $e^{-ity} H_0^{(1)}\left(\sqrt{k^2-\alpha^2}\sqrt{y^2+z_0^{\ 2}}\right)$ does not change appreciably over the impedance period a+b, then Nyberg showed that the solution can be written as:

$$\Psi(x,y,z) = -\frac{e^{ikR_1}}{4\pi R_1} - \frac{e^{ikR_2}}{4\pi R_2} + \frac{1}{2\pi}\int_{-\infty}^{+\infty} L_0'(\alpha,y,h) e^{i\alpha x} d\alpha \qquad (4)$$

where $L_0' = \frac{\beta_0 b + \beta_1 a}{a+b} L_0$ and $L_0(\alpha,y,h) = -\frac{k}{2\pi i}\int_{-\infty}^{+\infty} \frac{e^{i\left(ty + h\sqrt{k^2-\alpha^2-t^2}\right)} dt}{\left(\sqrt{k^2-\alpha^2-t^2} + k\beta_0\right)\sqrt{k^2-\alpha^2-t^2}}$.

In the particular geometry used in our experiment, the approximation translates into $a+b \ll \lambda$.

COMPARISON BETWEEN EXPERIMENTAL DATA AND PREDICTIONS

Laboratory measurements of the excess attenuation of sound from a point source over a single discontinuity between acoustically hard and finite impedance surface, as the proportion of hard surface is varied systematically, are compared to predictions from the various models presented previously. Source and receiver are 0.1 m above the ground and 1 m apart. The source is situated above the hard surface, and the receiver above the sand surface. The semi-empirical model and the boundary element code are found to give satisfactory agreement with the measurements. The predictions obtained from the Fresnel-zone model show more discrepancies when compared with experimental data. Fig. 1.a shows the results for 50% of hard surface.

Laboratory measurements of the excess attenuation of sound from a point source over a striped impedance with the same geometry as above are compared to the predictions from the four models. The results show that the Fresnel-zone model and the De Jong model are not adequate to predict excess attenuation spectra above multiple impedance discontinuities. However, both the Fourier transform method and the boundary element code give good agreement with the measured results. Fig. 1.b displays the results for 70% of hard surface.

CONCLUSIONS

The agreement between Nyberg's theory and the measurements shows that for the geometry used in the experiments, the ground effect due to striped impedance may be determined from that predicted by using the area-averaged impedance. An appropriate choice in percentage of hard ground cover allows minimisation of the excess attenuation in a chosen frequency domain as can be seen in Figs. 2.a-2.b for the case of a single discontinuity impedance ground. When a particular frequency range is targeted for minimal excess attenuation, an appropriate percentage of hard ground cover can be chosen, and a single discontinuity impedance ground will be preferred to a multiple discontinuity impedance ground because of the lower yield in excess attenuation. Figs. 3.a-3.b show this results in the case 70% of hard ground cover. For longer ranges of propagation over single discontinuity impedance, the semi-empirical model predicts A-weighted excess attenuation minima for specific proportions of hard surface when the source is not too close to the ground. Examples are given in Figs. 4.a-4.b respectively corresponding to a propagation range of 100 m, a receiver height 1.2 m, and source heights 0.1 m and 1 m.

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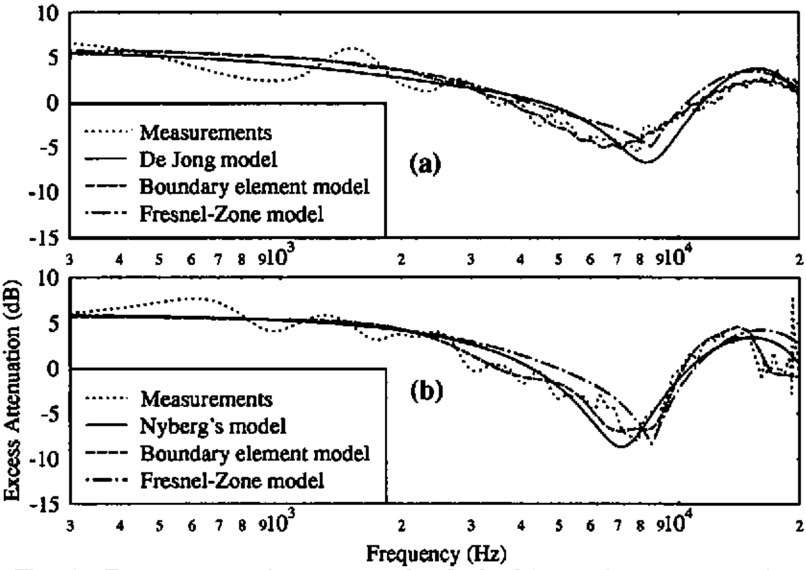

Fig. 1: Excess attenuation spectra for $h_s=h_r=0.1$m and a source-receiver separation distance of 1m. (a) shows the results for a 50% hard boundary with a single discontinuity and (b) for a 70% hard boundary with periodic impedance.

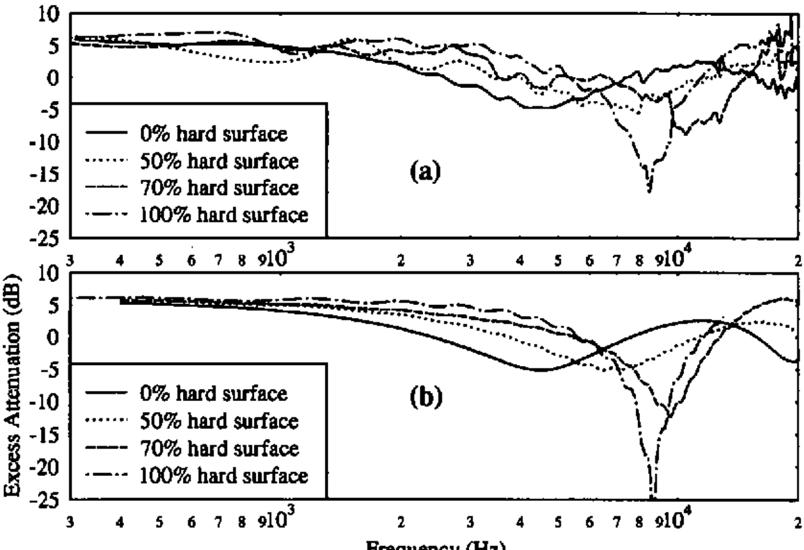

Fig. 2: Excess attenuation spectra for $h_s=h_r=0.1$m and a source-receiver separation distance of 1m for a single discontinuity. (a) shows the results of the measurements and (b) the results of the boundary element predictions.

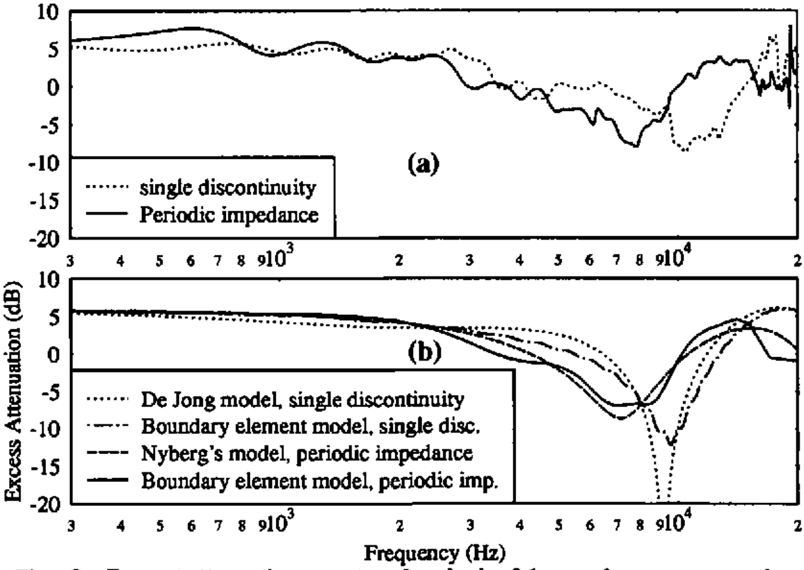

Fig. 3: Excess attenuation spectra for h_s=h_r=0.1m and a source-receiver separation distance of 1m for a 70% hard surface. (a) shows the results of the measurements and (b) the results of the predictions.

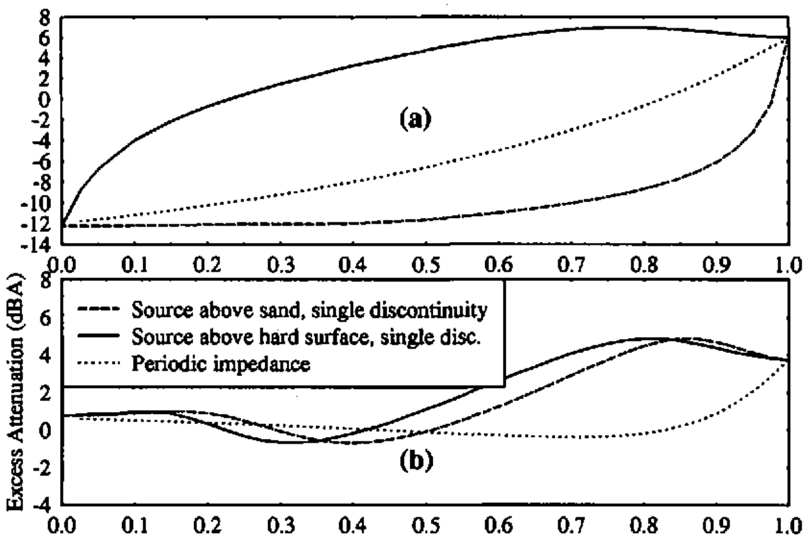

Fig. 4: Predicted excess attenuation spectra for h_r=1.2 m and a source-receiver separation distance of 100 m. (a) shows the results for h_s=0.1 m and (b) shows the results for h_s=1 m.