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NOISE PROPAGATION OVER GROUND - A NEW SOLUTION APPLIED TO NOISE BARRIER DIFFRACTION

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INTRODUCTION

This paper highlights the results of a two-phase study of acoustic diffraction by a barrier located on an impedance (locally-reacting) ground plane. The first phase was directed towards the development of a new asymptotic series solution to the problem of diffraction of a spherical-wave by an impedance covered plane. The solution is accurate and rapidly convergent, and is valid for all angles of incidence from 0° to 90°, and for all values of ground impedance (except $Z_N = Z/\rho c = 1$). The final solution is given in a form that is readily programmable. The second phase was to incorporate the new ground diffraction solution into a previously developed edge-diffraction model [1] based on Keller's Geometrical Theory of Diffraction and Kendig's impedance-covered half plane solution [2]. The net result was the "Edge-Plus-Images" model, which can be used to predict the attenuation or insertion loss of a barrier located on an impedance ground plane.

Ground Propagation Solution

A point source located at an arbitrary position above a perfectly flat impedance plane is shown in Fig. 1(a). To determine the field at a receiver point, an integral representation for the Helmholtz equation in cylindrical coordinates is solved using transforms, and a series of variable transformations is applied to the resulting inversion integral to make it readily integrable. A Taylor series expansion of an integrand term, followed by a term-by-term integration provide the final solution. The "asymptotic" nature of the solution arises from integrating the Taylor series beyond its radius of convergence. The derivation is rather lengthy and only the final result will be given here (see Ref. [3]). Thus, with several items defined in Fig. 1(a), the total field at the receiver is:

$$\phi_{tot}(P) = e^{ikR_1}/R_1 + Qe^{ikR_2}/R_2 \ , \qquad (1)$$

where
$$Q = 1 + \frac{2\beta}{(\beta + \sin\psi)} \sum_{n=0}^{\infty} T_n[e_1 E_n + K_n]$$

$$e_1 = i\sqrt{\pi}\ \lambda e^{-\lambda^2}\ \mathrm{erfc}(-i\lambda)\ ,\ \lambda = \sqrt{ikR_2}\ \sqrt{G}$$

$$T_n = \sum_{k=0}^{(n-2k)\geq 0} \binom{n-k}{k} a_{n-k} \left[\frac{4G}{H}\right]^{n-k} \ ,\ a_0 = 1\ ,\ a_m = \frac{(\frac{1}{2} - m)}{m} a_{m-1} \ ,$$

$$E_0 = 1\ ,\ E_1 = -1/2\ ,\ K_0 = 0\ ,\ K_1 = -1/2$$

$$E_m = -\frac{1}{2}E_{m-1} - \frac{(m-1)}{8ikR_2G}E_{m-2}\quad .\quad K_m = -\frac{1}{2}K_{m-1} - \frac{(m-1)}{8ikR_2G}K_{m-2}$$

and
$$\begin{matrix} G \\ H \end{matrix} = 1 + \beta\sin\psi \mp (1 - \beta^2)^{1/2}\cos\psi \ .$$

Using only the first (n=0) term in the series yields

$$Q = R_p + (1 - R_p)F\ ,\ F = 1 + e_1\ ,\ R_p = \frac{\sin\psi - \beta}{\sin\psi + \beta}\ , \qquad (2)$$

a form that has been reported by several authors. All complex roots are taken to give positive real parts.

Fig. 2 compares the attenuation at the receiver (total field divided by free field) predicted from four different forms of solution--the exact (numerical integration) solution, the asymptotic series given by Eq. (1), the first-term-only or "F-term" solution given by Eq. (2), and the "plane wave" solution in which $Q = R_p$, i.e., $F = 0$ in Eq. (2). In (a), the ground is very soft ($Z_N = 0.3 + i0.5$) and the path is very close to grazing ($\psi = 3°$). Above $kR_2 = 3$, the asymptotic series is indistinguishable from the exact solution, although the F-term form is also very accurate. Furthermore, even for such small Z_N and ψ, the plane wave solution is entirely satisfactory for $kR_2 > 60$. Fig. 2(b) illustrates the general trend that as source and receiver move away from the ground ($\psi = 10°$), the "ground effects" peak in attenuation shifts to the left, lowering the critical values of kR_2 above which each solution becomes accurate. As shown in (c), an increase in ground impedance causes the peak to shift to the right and also brings both the Q-term and the F-term solutions into very close agreement with the exact solution for kR_2 values as low as $kR_2 = 0.1$.

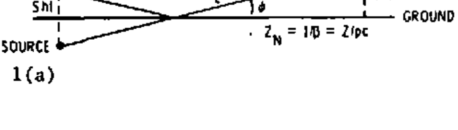

Fig. 1(a)

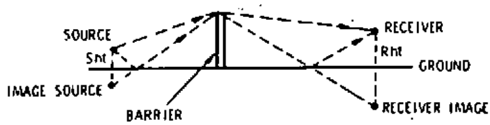

Fig. 1(b)

The Edge-Plus-Images Barrier Model

When a barrier is present between source and receiver, the influence of the ground reflections--both before and after diffraction by the barrier--must be accounted for. This is done by modeling the energy flow as a superposition of four half-plane diffracted ray paths: source-receiver, source-receiver image, source image-receiver, and source-receiver image [see Fig. 1(b)]. The strength of each ground-reflected ray is no longer unity but "Q", suitably calculated from Eq. (1) for the particular geometry.

Figure 3 compares the insertion loss (barrier-plus-ground divided by ground-only) predicted by the Edge-Plus-Images model using the first term in the series for the spherical wave reflection coefficient Q to that using the plane wave reflection coefficient R_p. Also shown are data calculated from half-plane diffraction theory alone without ground reflections. As expected, the Q and R_p data show their greatest differences for small kR (R is the total "up-and-over" source-to-receiver distance) or small barrier heights. It may be interesting, from a design standpoint, to note the indication in (c) of an "optimum" barrier height for a given set of conditions.

The question of when to use the full asymptotic series for Q, the first term only, or the simple plane wave reflection coefficient can only be answered after completing a thorough sensitivity study of all the parameters involved--barrier height, ground impedance, angle of incidence with the ground, angle of incidence with the barrier edge, kR, source and receiver heights-above-ground, and source and receiver offsets from the barrier.

REFERENCES

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[2] Kendig, R. P., "Acoustic Diffraction by an Impedance Covered Half-Plane," Ph.D. Thesis, The Pennsylvania State University, University Park, PA (1977).
[3] Nobile, M. A., "Acoustic Propagation and Barrier Diffraction Over an Impedance Plane," Ph.D. Thesis, The Pennsylvania State University, University Park, PA (1982).

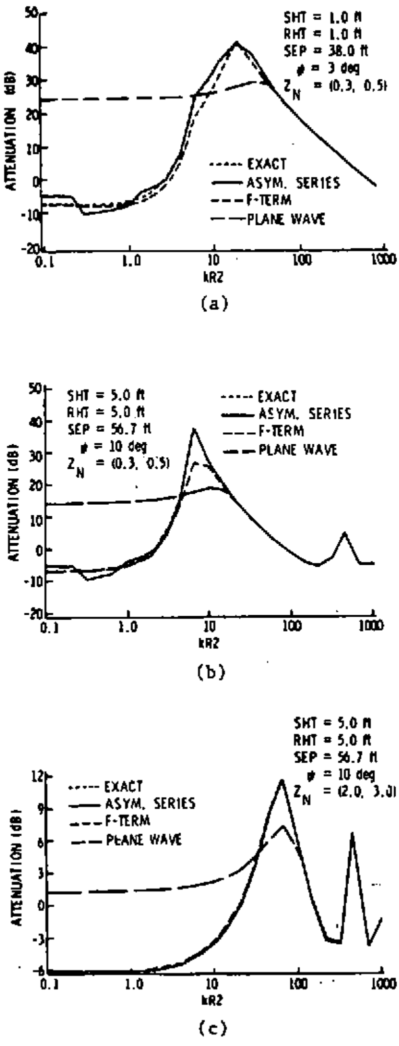
SHT = 1.0 ft
RHT = 1.0 ft
SEP = 38.0 ft
ϕ = 3 deg
Z_N = (0.3, 0.5)
EXACT
ASYM. SERIES
F-TERM
PLANE WAVE
ATTENUATION (dB)
kRZ
(a)
SHT = 5.0 ft
RHT = 5.0 ft
SEP = 56.7 ft
ϕ = 10 deg
Z_N = (0.3, 0.5)
EXACT
ASYM. SERIES
F-TERM
PLANE WAVE
ATTENUATION (dB)
kRZ
(b)
SHT = 5.0 ft
RHT = 5.0 ft
SEP = 56.7 ft
ϕ = 10 deg
Z_N = (2.0, 3.0)
EXACT
ASYM. SERIES
F-TERM
PLANE WAVE
ATTENUATION (dB)
kRZ
(c)

Fig. 2

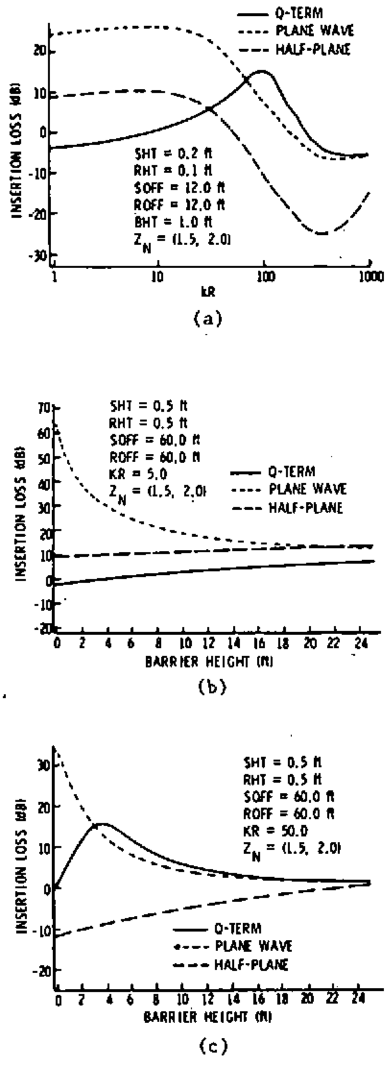
Q-TERM
PLANE WAVE
HALF-PLANE
SHT = 0.2 ft
RHT = 0.1 ft
SOFF = 12.0 ft
ROFF = 12.0 ft
BHT = 1.0 ft
Z_N = (1.5, 2.0)
INSERTION LOSS (dB)
kR
(a)
SHT = 0.5 ft
RHT = 0.5 ft
SOFF = 60.0 ft
ROFF = 60.0 ft
KR = 5.0
Z_N = (1.5, 2.0)
Q-TERM
PLANE WAVE
HALF-PLANE
INSERTION LOSS (dB)
BARRIER HEIGHT (ft)
(b)
SHT = 0.5 ft
RHT = 0.5 ft
SOFF = 60.0 ft
ROFF = 60.0 ft
KR = 50.0
Z_N = (1.5, 2.0)
Q-TERM
PLANE WAVE
HALF-PLANE
INSERTION LOSS (dB)
BARRIER HEIGHT (ft)
(c)

Fig. 3