Journal of KSNVE, Vol. 8, No. 1, pp. 146~156, 1998.

〈Original Paper〉

A Study on the Effects of Absorptive Treatments for the Highway Noise Barriers

도로교통소음의 방음벽 흡음효과에 관한 연구

Jae-Seok Kim*, Louis F.Cohn** and Kap-Soo Kim***
김 재 석 · 루이스 칸 · 김 갑 수

(Received September 22, 1997 ; Accepted December 4, 1997)

Key Words : Hard Noise Barrier(반사형소음방음벽), Absorptive Noise Barrier(흡음형소음방음벽), Effects of Absorption(흡음효과), Sound Absorbent Material(소음흡음재)

ABSTRACT

To mitigate excessive noise from highways, and high speed rail road, it is often necessary to construct a noise barrier. Absorptive barrier attenuation solution is obtained for the problem of diffraction of a plane wave sound source by a semi-infinite plane. A finite region in the vicinity of the edge has an highly absorbing boundary condition; the remaining portion of the half plane is rigid. The problem which is solved is a mathematical model for a hard barrier with an absorbing edge. If the wavelength of the sound is much smaller than the length scale associated with the barrier, the diffraction process is governed to all intents and purposes by the solution to a standard problem of diffraction by a semi-infinite hard plane with an absorbent edge. It is concluded that the absorbing material that comprises the edge need only be of the order of a wavelength long to have approximately the same effect, on the sound attenuation in the shadow side of the barrier. Traffic noise is composed of thousands of sources with varying frequency content. To simplify noise predictions when barriers are present, an effective frequency of 550Hz may be used to represent all vehicles. The wavelength of sound at f=550Hz for traffic noise is about 2 feet. According to the above conclusion, an absorptive highway noise barrier is only needed to cover approximately a 2 foot length of absorbing material. It would be more economical to cover only the region in the immediate vicinity of the edge with highly sound absorbent material.

* 정회원, 경일대학교 측지공학과
** University of Louisvelle 토목공학과
*** 정회원, 영남대학교 도시공학과

요 약

자동차의 폭발적인 증가와 아울러 경부고속전철시대를 맞이함으로 인하여 소음공해는 큰 사회적 문제로 대두되고 있다. 본 연구는 이러한 소음공해에 대한 해결책의 일환으로 효율적인 방음벽을 연구하는데 그 목적이 있다. 방음벽의 연구는 먼저 반사형 방음벽과 흡음형 방음벽에 대한 소음저감효과를 산정한 다음, 흡음재료를 사용함으로서 감소되는 소음저감 효과를 산정하는데 큰 의의가 있다. 본 연구결과에 의하면 방음벽의 높이에 비하여 음의 파장이 대체로 짧을 때는 방음벽의 상단부분에 흡음재를 설치하면 방음벽 전체에 흡음재를 설치한 것과 같은 효과가 있다는 결론을 얻었다. 도로교통소음은 평균주파수가 550Hz 이므로 이때 파장은 60cm 정도이다. 방음벽 높이를 4m로 설치했을 때 방음벽 상단에서 60cm 정도만 흡음재를 사용하면 4m전체의 방음벽에 흡음재를 사용한 것과 같은 효과가 있는 것으로 나타났다. 흡음재를 사용한 소음저감의 효과는 점음원이고 수음자의 위치가 135° 일 때 평균 8dB(A)정도이고, 선음원일때는 평균 3dB(A)정도의 효과가 있는 것으로 나타났다. 이러한 흡음형의 방음벽은 경제적일 뿐만 아니라 방음벽의 높이를 최소한 1m 이상 줄일 수 있으므로 국토를 고도로 이용해야 되는 우리 나라의 여건에 대단히 효과적인 방음벽이라 사료된다.

1. Introduction

Many people in Korea live quite close to high volume, high-speed highways and thus are exposed to high noise levels. To mitigate excessive noise from highways, it is often necessary to construct a noise barrier a device with sufficient mass and configuration to provide transmission loss and diffraction of noise propagating from a highway to a receptor.

More than 200 linear kilometers of noise barriers have been constructed in Korea during the last 20 years by the government authorities and the local government. The vast majority of these barriers have been vertical, reflective walls made of concrete, aluminum alloy, or steel. Clearly, there are many other options for noise barrier shapes than vertical reflective walls with knife-edge diffraction zones such as absorptive barriers, T-top barriers, slanted-top barriers, parallel barriers, Y-top barriers, etc.

For many years, experimental and theoretical studies have been carried out on the effect of noise reduction by an acoustic barrier and the efficiency of acoustical barriers has been the subject of research. Today, various models are available for calculating the insertion loss (IL) provided by thin and thick barriers, shaped barriers, waveguide barriers, and others. Some of this research was related to the prediction of the insertion loss of absorbent barriers. However, a review of the literature on this subject shows that there are still many uncertainties about the usefulness of covering barriers with absorbent materials.

The diffraction theory for half-planes with non-ideal boundary conditions including half-planes with impedance covered surfaces and for absorbent thin-wall barriers were developed by Senior,(1) Rawlins,(2) Hayek,(3) Pierce and Hadden,(4) Yuzawa,(5) Kendig,(6) Nobile, Hayek and Lawther,(7) Kindig and Hayek,(8) Fujiwara,(9) Hayek and Grosh.(10)

The solution of this research is obtained for the problem of diffraction of a plane wave sound source by a semi-infinite plane. A finite region in the vicinity of the edge has an highly absorbing boundary condition; the remaining part of the half plane is hard(rigid). The problem which is solved is a mathematical model for a hard barrier with an absorbing edge.

This research presents a method for calculating the effect of a thin barrier covered with highly absorbent material on the both sides by the solution to a standard problem of diffraction by a semi-infinite hard plane with an absorbent edge. It is concluded that the absorbing material that comprises the edge need only be of the order of a wavelength long to have approximately the same effect, on the sound attenuation in the shadow side of the barrier, as a completely absorbent barrier.

Traffic noise is composed of thousands of sources with varying frequency content. To simplify noise predictions when barriers are present, an effective frequency of 550 Hz may be used to represent all vehicles. The wavelength of sound at f=550 Hz for traffic noise is about 2 feet (0.624 m = 343m/550Hz).

According to the above conclusion, an absorptive highway noise barrier is only needed to cover approximately a 2 foot length of absorbing material. It would be more economical to cover only the region in the immediate vicinity of the edge with highly sound absorbent material.

2. Hard Noise Barrier Attenuation

A solution of this research is obtained for the problem of the diffraction of a plane wave sound source by a semi-infinite half plane. The mathematical problem which is solved is an approximate model for a hard noise barrier.

Figure 1 represents a sketch of the geometry for a hard noise barrier.

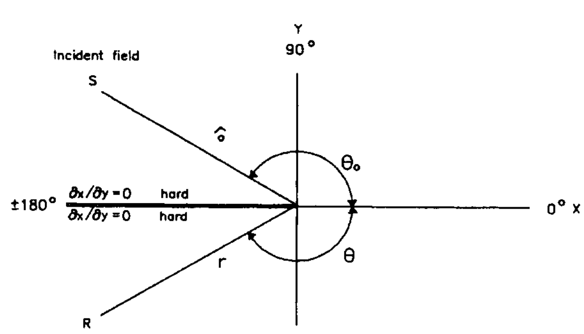

Fig. 1 Sketch of the geometry for a hard noise barrier

A semi-infinite plane is assumed to occupy $y = 0$, $x \le 0$, $-\infty < z < +\infty$; see Fig. 1. The half plane is assumed to be infinitely thin. The perturbation velocity, u, of the irrotational sound wave can be expressed in terms of a velocity potential $\Psi(x,y)$ by $u = \mathrm{grad}\,\Psi(x,y)$. The resulting pressure(p) in the sound field is given by $p = -\rho_0\, \partial\Psi(x,y)/\partial t$, where ρ_0 is the density of the ambient medium.

Without going through the detailed analysis the asymptotic far field expression $\phi_H(x,y)$ as $kr \to \infty$ is given below. Where k is wavenumber. The technique for obtaining these results can be found in the Reference.[11] Thus if

$$x = r\cos\theta, \quad y = r\sin\theta \quad -\pi < \theta < \pi$$

$F(Z) = e^{-iz^2}\int_z^{\infty} e^{it}dt$ then, Hard far field

for $0 < \theta_0 < \pi$

$$\Psi_H(r,\theta) = D_H\ (-\pi < \theta < \theta_0 - \pi) \tag{1}$$

where

$$D_H = \frac{e^{i(kr-\pi/4)}}{\sqrt{(2\pi ikr)}}\,\frac{\sqrt{(1-\cos\theta)}\sqrt{(1-\cos\theta_0)}}{(\cos\theta+\cos\theta_0)}\,2|Q|F(|Q|)$$

$$Q = \frac{\sqrt{kr}}{2}\,\frac{(\cos\theta+\cos\theta_0)}{\sin\theta}$$

$$F(|Q|) = i/(2|Q|) + O(|Q|^{-3})$$

The hard single noise barrier attenuation in decibels given by Eq. (1) for an observer in the far field is calculated by Eq. (2),

$$(\Delta_H)_i = 20\log_{10}\Psi_H(r,\theta) \tag{2}$$

where

$(\Delta_H)_i$ is the point source attenuation for the i^{th} class of vehicles.

Thus, the hard barrier attenuation for the line source may be written as:

$$\Delta_{HB} = 10\log\{[1/(\phi_R - \phi_L)]\int_{\phi_L}^{\phi_R}[10^{-\Delta Hi/10}]d\phi\} \tag{3}$$

where ϕ_L and ϕ_R are the angles at the

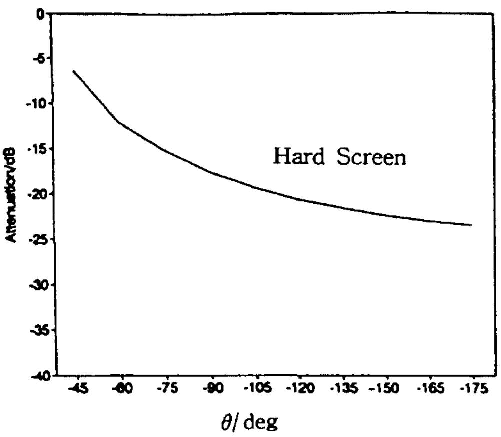

Fig. 2 The Attenuation in the shadow region of a hard barrier ($kr = 10\pi$ and $\theta_0 = 135^\circ$)

receiver between the normal line to the barrier and the left and right endpoints of the barrier, respectively (as viewed from the receiver), and Δ_{Hi} is the point source hard barrier attenuation at any point i along the line. Fig. 2 represents the attenuation in the shadow region of a hard barrier for $kr = 10\pi$, the angle of incidence is taken as 135° .

3. Absorptive Noise Barrier Attenuation

The Absorptive single barrier attenuation solution is obtained for the problem of diffraction of a plane wave sound source by a semi-infinite plane. A finite region in the vicinity of the edge has an highly absorbing boundary condition; the remaining portion of the half plane is rigid (hard). The problem which is solved is a mathematical model for a hard barrier with an absorbing edge. If the wavelength of the sound is much smaller than the length scale associated with the barrier, the diffraction process is governed to all intents and purposes by the solution to a standard problem of diffraction by a semi-infinite hard plane with an absorbent edge. Under the above approximations a mathematical model for a rigid barrier with a highly absorbing edge is given by a

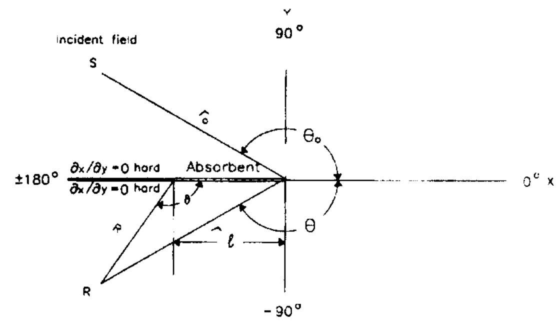

Fig. 3 Sketch of the geometry for an absorptive noise barrier

standard problem of diffraction by a semi-infinite rigid half-plane with a highly absorbing edge.

The aim here is to solve this mixed boundary value problem. A semi-infinite plane is assumed to occupy $y = 0$, $x \leq 0$; see Fig. 3. The half plane is assumed to be infinitely thin, and over the interval $(-\ell < x < 0)$ there is a highly absorbing substance; the remainder, $-\infty < x < -\ell$, of the half plane is hard (rigid). The perturbation velocity, u, of the irrotational sound wave can be expressed in terms of a velocity potential $\Psi(x,y)$ by $u = \text{grad}\ \Psi(x,y)$. The resulting pressure(p) in the sound field is given by $P = -\rho_0\ \partial\Psi(x,y)/\partial t$, where ρ_0 is the density of the ambient medium.

It is assumed that a given incident sound source potential field, $\phi_0(x,y)e^{-iwt}$, is diffracted by the semi-infinite plane. In what follows the time harmonic variation factor, e^{-iwt}, is omitted. Then the boundary value problem becomes one of solving the wave Eq. (4)

$$\{\partial^2/\partial x^2 + \partial^2/\partial y^2 + k^2\}\,\Psi(x,y) = 0 \tag{4}$$

subject to the boundary conditions

$$\partial\Psi(x,0^{\pm})/\partial y = 0 \qquad x < -\ell, \tag{5}$$

$$(\partial/\partial y \pm ik\beta)\ \Psi(x,0^{\pm}) = 0 \quad -\ell < X < 0 \tag{6}$$

$$\Psi(x,0^+) = \Psi(x,0^-), \quad \partial\Psi(x,0^+)/\partial y = \partial\Psi(x,0^-)/\partial y \quad x>0 \tag{7}$$

where $\beta=\rho_0 c/z$, $Re(z)>0$. z is the acoustic impedance of the half plane.

It is assumed that a solution can be written in the form

$$\Psi(x,y) = \phi_0(x,y) + \phi(x,y), \tag{8}$$

where $\phi(x,y)$ represents the perturbed field due to the presence of the half plane. For analytic convenience one can write $k = k_r + ik_i(k_r, k_i>0)$, in which case for a unique solution of the boundary value problem of Eqs. (4)~(8), one also requires the satisfaction of the radiation condition

$$\phi(x,y) = o(e^{-kir}/\sqrt{r}) \quad \text{as} \quad r = (x^2+y^2)^{1/2} \to\infty \tag{9}$$

and also the "edge condition"

$$\Psi(x,0) = 0(4) \quad \text{and}$$
$$\partial\Psi(x,0)/\partial y = 0(x^{-1/2}) \quad \text{as} \quad x\to 0^+$$
$$\Psi(x,0) = 0(4) \quad \text{and}$$
$$\partial\Psi(x,0)/\partial y = 0(x+\ell)^{-1/2} \text{as } x\to -\ell \tag{10}$$

In the case for which $k\ell = 0$ and $k\ell = \infty$, each corresponds to the hard and absorbing half plane solutions, respectively.

Solution of the boundary value problem, which is used the spatial Fourier transform of the velocity potential.[2]
and its inverse as

$$\Phi(\alpha,y) = \int_{-\infty}^{\infty}\phi(x,y)e^{i\alpha x}dx \tag{11}$$

$$\phi(x,y) = \int_{-\infty+i\tau}^{\infty+i\tau}\Phi(\alpha,y)e^{-i\alpha x}d\alpha \tag{12}$$

Where $\alpha=\sigma+i\tau$. The transform (11) and its inverse (12) will exist provided $-k_i<\tau<k_i$; this follows from the radiation condition(9).

The solution to the boundary value problem is now known and is given by

$$\Psi(x,y) = \phi_0(x,y) + \frac{1}{2\pi}\int_{-\infty+i\tau}^{\infty+i\tau} A(\alpha)e^{-i\alpha x+iky}d\alpha \quad (y>0) \tag{13}$$

$$= \phi_0(x,y) + \frac{1}{2\pi}\int_{-\infty+i\tau}^{\infty+i\tau} B(\alpha)e^{-i\alpha x-iky}d\alpha \quad (y<0) \tag{14}$$

For the purposes of plotting the polar diagram of the scattered far field, the expressions (13) and (14) are approximated asymptotically evaluated for $kr\to\infty$. This is achieved by using the result:

$$\frac{1}{2\pi}\int_{-\infty+i\tau}^{\infty+i\tau}\frac{f(\alpha)e^{-i(\alpha x-k|y|)}}{k(\alpha-k\cos\theta_0)}d\alpha$$
$$\approx \frac{f(-k\cos\Theta)}{(k\sqrt{2\pi k\rho})}\left[\frac{2|N|F(|N|)}{(\cos\Theta+\cos\theta_0)}\right]e^{i(k\rho+\frac{\pi}{4})}$$
$$+ sgn(\cos\theta_0)H[-\cos\theta_0(\cos\theta_0+\cos\Theta)]$$
$$\times\frac{f(k\cos\theta_0)}{k|\sin\theta_0|}e^{-ik(x\cos\theta_0-|y|\sin\theta_0)} \tag{15}$$

as $k\rho\to\infty$, where
$x=\rho\cos\Theta$, $y=\rho\sin\Theta$, $0<\Theta<\pi$
Θ is a function of θ, $\Theta = \pm(\pi-\Theta_0)$

$$F(|N|) = e^{-iN^2}\int_{|M}^{\infty}e^{it^2}dt, \quad |N| = \sqrt{\frac{k\rho}{2}}\left|\frac{\cos\Theta+\cos\theta_0}{\sin\Theta}\right|$$

The above result is obtained by an application of the saddle point method, modified slightly because of the presence of the pole $\alpha = k\cos\theta_0$ [reference(11)]. When N is large the above result (15) can be simplified by using the asymptotic expansion for the Fresnel integral:

$$F(|N|) = i/(2|N|) + O(|N|^{-3}) \tag{16}$$
$$\text{Where, } |N|\to\infty$$

Finally, Expression (16) can be used in expression (15) if no pole occurs at $\alpha = k\cos\theta_0$ in the integrand. Thus, upon using the results(15) and (16), for $0<\theta_0<\pi$, expressions (13) and (14) yield (2),(11), (12), and (13)

$$\Psi_A\ (r,\theta) = D_A\ (-\pi<\theta<\theta_0-\pi), \tag{17}$$

where $x = r\cos\theta$, $y = r\sin\theta$, $-\pi \le \theta \le \pi$,

$$D_A = \frac{e^{i(kr-\pi/4)}}{\sqrt{2\pi kr}} \cdot \frac{2|Q|F(|Q|)}{(\cos\theta + \cos\theta_0)} \cdot \frac{\{L_+(k\cos\theta_0)\}^{-1}}{KL_+(\cos\theta)} \left(1 + \frac{\sqrt{1-\cos\theta_0}\sqrt{1-\cos\theta}}{\beta}\right) + \frac{e^{i(kr-\pi/4)}}{\sqrt{2\pi kr}} G_2(\theta, \theta_0) + \frac{e^{i(kR-\pi/4)}}{\sqrt{2\pi kR}} \cdot G_2(\vartheta, \theta_0) \quad (18)$$

In the above expressions for D_A the various quantities appearing are given by

$$Q = \frac{\sqrt{kr}}{2}\frac{(\cos\theta + \cos\theta_0)}{\sin\theta}$$

$$R^2 = r^2 + \ell^2 + 2r\ell\cos\theta$$

$$\vartheta = \mathrm{sgn}(\theta)\cos^{-1}[(\ell + r\cos\theta)/R]$$

$$F(|Q|) = i/(2|Q|) + O(|Q|^{-3})$$

$$L_+(k\cos\theta) = \frac{\sqrt{(1+\text{ß})}}{\sqrt{(1+\cos\text{ß})}} \exp\left\{\frac{\text{ß}}{2\pi\sqrt{(1-\text{ß}^2+M^2\text{ß}^2)}}\left[(M-\nu_1)\int_{\frac{\pi}{2}}^{\theta}\frac{\mu-(\cos^{-1}(\nu_1)/\sqrt{(1-\nu_1^2)}]\sin\mu)\,d\mu}{(\nu_1-\cos\mu)} - (M-\nu_2)\int_{\frac{\pi}{2}}^{\theta}\frac{[\mu-(\cos^{-1}(\nu_2)/\sqrt{(1-\nu_2^2)}]\sin\mu)\,d\mu}{(\nu_2-\cos\mu)}\,d\mu\right]\right\} \quad (19)$$

$$L_+(k\cos\theta_0) = \frac{\sqrt{(1+\text{ß})}}{\sqrt{(1+\cos\theta_0)}} \exp\left\{\frac{\text{ß}}{2\pi\sqrt{(1-\text{ß}^2+M^2\text{ß}^2)}}\left[(M-\nu_1)\int_{\frac{\pi}{2}}^{\theta_0}\frac{[\mu-(\cos^{-1}(\nu_1)/\sqrt{(1-\nu_1^2)}]\sin\mu)\,d\mu}{(\nu_1-\cos\mu)} - (M-\nu_2)\int_{\frac{\pi}{2}}^{\theta_0}\frac{[\mu-(\cos^{-1}(\nu_2)/\sqrt{(1-\nu_2^2)}]\sin\mu)\,d\mu}{(\nu_2-\cos\mu)}\,d\mu\right]\right\} \quad (20)$$

$$\nu_1 = 1/(1+\text{ß}^2M^2)\{M\text{ß}^2+\sqrt{1-\text{ß}^2+M^2\text{ß}^2}\}$$

$$\nu_2 = 1/(1+\text{ß}^2M^2)\{M\text{ß}^2-\sqrt{1-\text{ß}^2+M^2\text{ß}^2}\}$$

$\text{ß} = \beta(\sqrt{1-M^2})$

$\beta = \rho 0\, c/Z$, c is the velocity of sound.

M $(=U/C)$ is the Mach number.

ß is complex.

$$G_2(\theta, \theta_0) = k2^{-1/2}|\sin\theta| L_+^2(k)L_-(k\cos\theta)\{S_1(k) - S_2(k) + \psi_+(k) + \omega_+(k)\}W(-k\cos\theta) - \sqrt{k|\sin\theta|}\,L_+(k)L_-(k\cos\theta)\sqrt{(1-\cos\theta)}\,\Lambda_-(-k)W(-k\cos\theta)/(i\beta) \quad (21)$$

$$G_2(\vartheta, \theta_0) = |\sin\vartheta| L_+(k)L_+(k\cos\vartheta)\{k/2L_+(k)(S_1(k)+S_2(k)+\phi_+(k) - \omega_+(k)\} \pm i/\beta \langle \sin\theta_0/(1-\cos\theta_0) + (2k)^{1/2}\Lambda_+(k)\rangle\} W(k\cos\vartheta) \quad (22)$$

The expression for the total acoustic far field, given by the expressions (17) to (22), together with Fig. 4, gives a picture of the physical fields. The term D_A represents the fields diffracted from the edge $x = -\ell$. The terms involving r and θ represent the contribution to the diffracted field from the edge x=0. The terms involving R and ϑ give the field diffracted by the joint $x = -\ell$.

In the numerical calculation of D_A the last two terms involving G_2 were dropped. This was done because of the considerable amount of numerical calculation required for these terms which have a negligible effect on the far field for $k\ell > 1$.[13]
This research for the $k\ell$ $(2\pi/2 \times 2 = 6.28)$ is mush larger than 1.

This result is achieved by the following

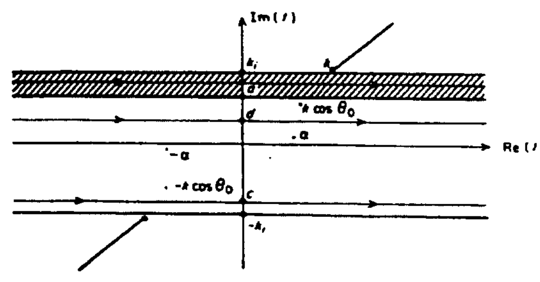

Fig. 4 Illustration of locations of the poles in the complex plane[(2)]

Eq. (23):

$$D_A = \frac{e^{i(kr-\pi/4)}}{\sqrt{2\pi kr}} \cdot \frac{2|Q|F(|Q|)}{(\cos\theta + \cos\theta_0)} \cdot \frac{\{L_+(k\cos\theta_0)\}^{-1}}{KL_+(\cos\theta)} \left(1 + \frac{\sqrt{1-\cos\theta_0}\sqrt{1-\cos\theta}}{\beta}\right) \quad (23)$$

As the reactive part of the specific impedance increase $L_+(\cos\theta)$ for a fixed value of M; there is no noticeable change to the lobe in the region $-\pi < \theta < 0$.[12]

Equation (23) is presented by the research as the solution to the single absorptive barrier problem. The parameter $L_+(k\cos\theta, \theta_0)$ in Eq. (23) is calculated as part of this research. The computer program shown in the reference[14] calculates the parameter for automobiles, medium trucks, and heavy trucks.

Figures 5, 6, and 7 give the attenuation of the sound field, $20\log_{10}|\Psi_A(r,\theta)|$, in the $(-\pi < \theta < \theta_0 - \pi)$, in the shadow region of the screen for $kr = 10\pi$, $\theta_0 = 135°$, $k\ell = 0$, 2π, and various values of impedance (ζ).

The presence of an acoustically absorbing lining on a surface is usually described by an impedance relationship between the pressure (P) and the normal velocity fluctuation on the lining surface. This gives rise to a boundary condition on the absorbing lining of the form

$$\partial p/\partial n = ik\beta p, \quad [\,\mathrm{Re}\ (\beta) > 0\,]$$

where the sound wave has harmonic time variation e^{-iwt} and $k = w/c$, c is the velocity of sound, n the normal pointing into the lining, and β the complex specific admittance of the acoustic lining. An acoustically hard (or perfectly reflecting) surface has a vanishing admittance, $|\beta| \to \infty$, and an acoustically soft surace is given by $|\beta| \to \infty$.

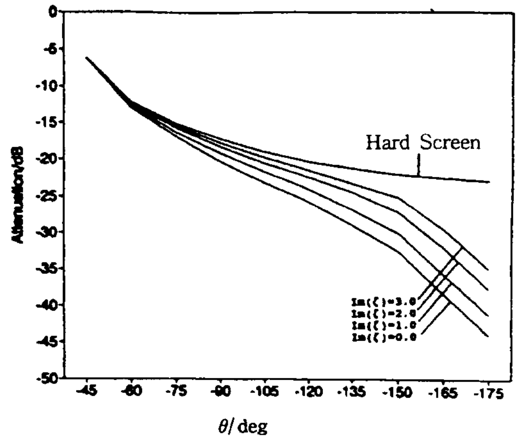

Fig. 5 Attenuation given by a hard half plane with an absorbent edge[$kr = 10\pi$ $\theta_0 = 135°$, $k\ell = 2\pi$ real impedance $(\zeta) = 0.5$), and various of image impedance (ζ)]

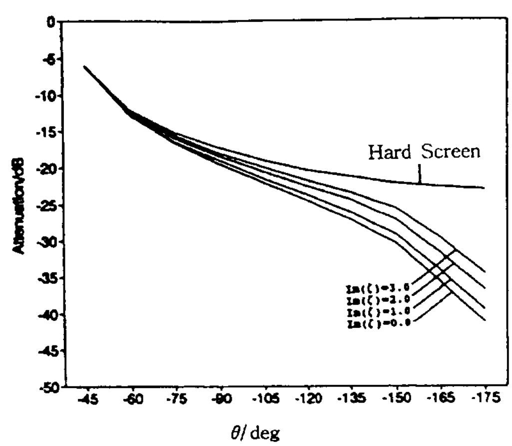

Fig. 6 Attenuation given by a hard half plane with an absorbent edge [$kr = 10\pi$, $\theta_0 = 135°$, $k\ell = 2\pi$ real impedance $(\zeta) = 1.0$), and various of image impedance (ζ)]

From Figs. 5, 6, and 7, it can be seen that the level of attenuation, compared to that of a hard half plane, in the shadow region is greater the larger $|\beta| = |\zeta|^{-1}$ is. It has already been shown in reference [13] that provided $k\ell > 1$ the field in the shadow of the screen is to all intents and purposes the same as for $k\ell = \infty$.

For an absorbing material the following

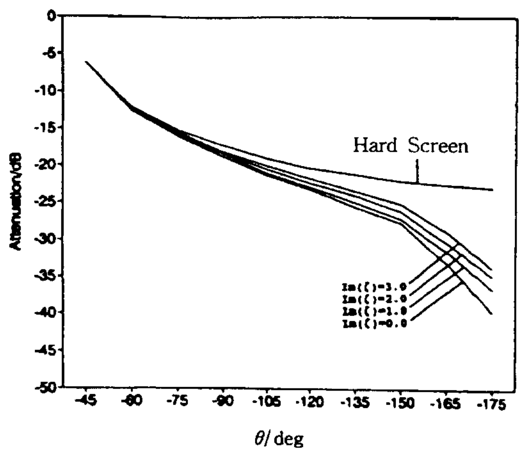

Fig. 7 Attenuation given by a hard half plane with an absorbent edge [$kr=10\pi$ $\theta_0=135^{\circ}$, $k\ell=2\pi$ real impedance $L(\zeta)=2.0$), and various of image impedance (ζ)]

values of specific impedance $\zeta=\xi+i\eta$ $(=1/\beta)$ seen to be of practical importance: fibrous sheet, $\xi=0.5$, $-1<\eta<3$; perforated steel, , $0<\xi<2$, $-1<\eta<3$. Where η is the real specific impedance. The impedance ζ of the lining at the edge of the screen is chosen to give the softest lining $\zeta\rightarrow 0$ mechanically possible.

From the graphical results one can conclude that the sound attenuation in the shadow region increases as $|\beta|$ increases; the softer the absorbent material becomes, which makes up the edge, the greater the attenuation. It is only necessary to apply the absorbent material to within a wavelength of the edge of the rigid screen to have the same effect, on the sound attenuation tin the shadow region, as a screen covered completely with absorbent material.

Traffic noise is composed of thousands of sources with varying frequency content. To simplify noise predictions when barriers are present, an effective frequency of 550 Hz may be used to represent all vehicles. Also, the wavelength of sound at f=550 Hz for traffic noise is about 2 feet (0.642 m = 343m/55 Hz). According to the above conclusion, an absorptive highway noise barrier is only needed to cover approximately a 2 foot length of absorbing material. It would be more economical to cover only the region in the immediate vicinity of the edge with highly sound absorbent material.

Experimental work by Fujiwara[9,15], Butler[16], Dagile,[17] and Maekawa[18] would seem to fully support the above conclusions.

Thus, the attenuation of absorptive single noise barrier can be calculated by Eq.(24),

$$(\Delta_A)_i = 20\ \log_{10}[\Psi_A(r,\theta)] \quad (24)$$

$(\Delta_A)_i$ is the point source attenuation for the i^{th} class of vehicles.

Thus, the absorptive barrier attenuation for the line source may be written as:

$$\Delta_{AB} = 10\log\{[1/(\phi_R-\phi_L)]\int_{\phi_L}^{\phi_R}(10^{(-\Delta Ai/10)})d\phi\} \quad (25)$$

where ϕ_L and ϕ_R are the angles at the receiver between the normal line to the barrier and the left and right endpoints of the barrier, respectively (as viewed from the receiver), and Δ_{Ai} is the point source absorptive barrier attenuation at any point i along the line.

4. Effects of Absorption

The Effect of Absorption EA is found through the difference in the sound pressure level in the shadow zone resulting from the replacement of a hard barrier with an absorbing one; that is, the difference between the excess attenuation by the hard barrier $[Att]_H$ and the excess attenuation by the absorptive barrier$[Att]_A$. Then this effect is expressed by:

$$EA = [Att]_A - [Att]_H \ (dB) = 20\log_{10}[\Psi_A(r,\theta)] - 20\log_{10}\Psi_H(r,\theta) \quad (26)$$

where $[Att]_A$ is attenuation by absorptive barrier, and $[Att]_H$ is attenuation by the hard barrier.

In the practice of traffic noise control, it is useful to obtain the effect of absorption EA for an incoherent line source. The effect of absorption for line source may be written as:

$$(EA)_L = [Att]_{LA} - [Att]_{LH} = 10\log\{[1/(\phi_R - \phi_L)]\int_{\phi_L}^{\phi_R}(10^{(-\Delta Ai/10)}d\phi\} - 10\log\{[1/(\phi_R - \phi_L)]\int_{\phi_L}^{\phi_R}(10^{-\Delta Hi/10})d\phi\} \quad (27)$$

where $[Att]_{LA}$ is attenuation by the absorptive barrier for line source, and $[Att]_{LH}$ is attenuation by the hard barrier for line source.

The excess attenuation of noise by an absorptive barrier $[Att]_A$ is given by the sum of the excess attenuation by a hard barrier $[Att]_H$ and the effect of absorption, that is:

$$[Att]_A = [Att]_H + [EA] \ (dB) \quad (28)$$

where EA is effect of absorption ($[Att]_A$ - $[Att]_H$).

The excess attenuation of noise by an absorptive barrier for line source $[Att]_{LA}$ is given by the sum of the excess attenuation by a hard barrier for line source $[Att]_{LH}$ and the effect of absorption for line source $[EA]_L$. That is:

$$[Att]_{LA} = [Att]_{LH} + [EA]_L = [Att]_{LH} + [(Att)_{LA} - (Att)_{LH}] = 10\log\{[1/(\phi_R - \phi_L]) \int_{\phi_L}^{\phi_R}(10^{-\Delta Hi/10})d\phi\} + [10\log\{(1/(\phi_R - \phi_L)]\int_{\phi_L}^{\phi_R}(10^{(-\Delta Ai/10)})d\phi\} - 10\log\{(1/(\phi_R - \phi_L))\int_{\phi_L}^{\phi_R}(10^{-\Delta Hi/10})d\phi\}] \quad (29)$$

where $[Att]_{LA}$ is excess attenuation by the absorptive barrier for line source, and $[Att]_{LH}$ is excess attenuation by the hard barrier for line source. $[EA]_L$ is effect of absorption ($[Att]_{LA}$ - $[Att]_{LH}$).

5. Summary

The use of absorptive materials in single barriers is an effective way to increase the insertion loss of the barrier. The absorptive material is only needed in the upper zone of the barrier, which is the size of the dominant wavelength (generally about 2 feet = 0.624 m = 343m/550Hz).

The use of absorbent material can also help reduce the height of a barrier in order to achieve the desired insertion loss. According to this research, Single-wall absorptive barriers may provide up to approximately 4 dBA in additional insertion loss for receivers deep in the shadow zone when the distance between source position and receiving position from the barrier is approximately same, which is used in highly absorbent material.

The provision of a completely absorbent screen presents several difficulties, among them the cost of construction and maintenance. However, this research since diffraction phenomena are governed in general by conditions at the diffracting edge, proved that the improved attenuation for the absorbent screen could be obtained simply by treating a region in the neighborhood of the edge (2 ft for transportation noise) with highly absorbing material. It would be more economical to design for highway absorptive noise barriers than the other types of design.

In addition, barrier performance can generally be improved by the use of absorptive treatments. When sound absorptive materials are used outdoors in highway situations, they must be resistant to weather conditions, which are particularly severe when there are freeze-thaw cycles, acts of vandalism, impacts from vehicles, and the presence of chlorides from snow plowing operations and spray. From an acoustical point of view a relatively high sound absorption would be desired in the range 500 to 2000 Hz, where the A-weighted traffic noise contains much of its energy.

6. Research Findings

This research has resulted in the following findings:

(1) The Effect of Absorption (EA) is found through the difference in the sound pressure level in the shadow zone resulting from the replacement of a hard barrier with an highly absorbing materials.

(2) It is only necessary to apply the absorbent material to within a wavelength (about 2 ft) of the rigid screen to have the same effect, on the sound attenuation in the shadow region , as a screen covered completely with absorbent material.

(3) The results show that, when the angles of diffraction are significant, the insertion loss (IL) of a hard barrier can be substantially increased by covering with highly absorbent material.

(4) From Fig. 2, 5, 6, and 7, it can be seen that the level of attenuation, compared to that of a hard half plane, in the shadow region is greater larger angle θ.

(5) The use of highly absorbent material for highway noise barriers can also help reduce the height of a barrier in order to archive the desired insertion loss. It would be more economical to design for highway noise barriers than the other types.

References

(1) Senior, T.B.A., 1956, Diffraction by a Semi-Infinite Metallic Sheet, Proc., Roy. Soc (Lond), Vol. A213 pp. 436~458.

(2) Rawlins, A.D., 1976, Diffraction of Sound by a Rigid Screen with an Absorbent Edge, Journal of Sound and Vibration, Vol. 47 pp. 523~541.

(3) Hayek, S.I., 1975, Acoustic Diffraction by Impedance Edges. Journal of Acoustical Society of America, Vol.58(Supplement 1) p.S129.

(4) Pierce, A.D. & Hadden, W.J.Jr, 1975, Noise Diffraction Around Barriers of Finite Acoustic Impedance. Pro.3rd Intelligency Symposium on University Research in Transportation Noise, U.s Department of Transportation, pp. 50~58

(6) Kendig, R.P., 1977, Acoustic Diffraction by an Impedance Covered Half-Plane,Ph.D Dissertation, The Pennsylvania State University, University Park, PA.

(7) Nobile, M.A., Hayek, S.I. & Lawther, J.M., 1980, A Comprehensive Model for the Straight Edge Noise Barrier, Journal of Acoustical Society of America, Vol.68 (Supplement 1) S54.

(8) Kendig, R.P.& Hayek, S.I., 1981, Diffraction by a hard-soft Barrier, Journal of Acoustical Society of America, Vol. 70 pp. 1156~1165.

(9) Fujiwara, K, Ando. Y & Maekawa.Z, 1977, Noise Control by Barriers Part 2: Noise Reduction by an Absorptive Barrier, Applied Acoustics, Vol. 10 pp. 167~179.

(10) Hayek,S.I.& Grosh, K., 1986, Influence of Ground Absorption on Barrier Attenuation, Proc. Internoise '86, Cambridge, MA, pp. 447~452.

(11) Rawlins, A.D. 1974, The Solution of a Mixed Boundary Value Problem in the Theory of Diffraction by a Semi-infinite Plane, Proc., Roy. Soc. (Lond.).Vol. A346, pp. 469~484.

(12) Rawlins, A.D., 1974, Acoustic Diffraction by an Absorbing Semi-Infinite Half Plane in a Moving Fluid, Proc.R.S.E, Vol. (A)72

pp. 337~357.
(13) Rawlins, A.D., 1976, Diffraction of Sound by a Rigid Screen with a Soft or Perfectly Absorbing Edge, Journal of Sound and Vibration, Vol. 45 pp. 53~67.
(14) Kim,J.S., 1992, Performance of Absorptive Treatments for Single Highway Noise Barriers, Ph.D Dissertation, The University of Kentucky.
(15) Fujiwara, Kyoji., 1991, Sound Shielding Efficiency of a Barrier with a Cylinder at the Edge, Noise Control Engineering, Vol. 37 pp. 5~11.
(16) Butler, G.F., 1974, A Note on Improving the Attenuation Given by a Noise Barrier, Journal of Sound and Vibration, Vol. 32(3), pp. 367~369.
(17) Daigle, G.A., 1989, Insertion Loss of Absorbent Barriers on Ground, Journal of Acoustical Society of America, Vol. 86(3) pp. 1060~1064.
(18) Maekawa, Z., 1966, Noise Reduction by Screens, Memoirs of Faculty of Engineering, Kobe University, No.11, pp.29~53.