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ATTENUATION OF SOUND REFLECTIONS DUE TO DIFFRACTION

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1. Introduction

Freely suspended reflectors are often used in room acoustics; however, the sound reflections from such surfaces with free edges can be attenuated considerably due to diffraction. Similar problems are met in geometric models for calculation of noise levels where reflecting surfaces of finite size are involved.

A general survey of the attenuation due to distance, absorption and curvature of the surface is found in ref. [1] or ref. [2]. In the following, only the attenuation due to diffraction is considered, i.e. the surface is assumed to be totally reflecting and plane.

2. Kirchhoff-Fresnel approximation to diffraction

A spherical sound wave emitted from a point source Q is reflected from a surface of finite dimensions as shown in fig. 1. Generally, the reflected sound field at the receiver P can be calculated from a surface integration covering all parts of the reflecting surface. Using the Kirchhoff-Fresnel approximation it appears that the intensity of the reflected sound can be expressed as a reflection coefficient K multiplied by the intensity reflected from a corresponding infinite surface, ref. [3]. Considering a rectangular surface the attenuation due to diffraction is:

$$\Delta L_{\mathrm{diffr}} = 10 \log K = 10 \log(K_1 \cdot K_2) \qquad (1)$$

where K_1 and K_2 are reflection coefficients referring to each of the two

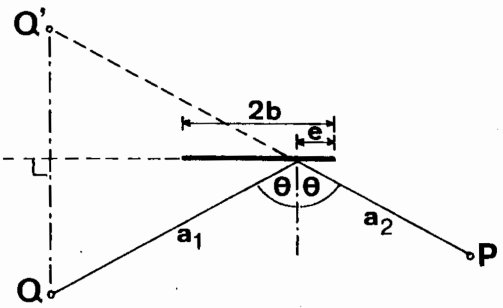


Fig. 1 *Section through reflecting surface showing the projection of source Q and receiver P. Q' is the mirror source.*

ortogonal sections through the surface. Thus, the two sections can be treated independently.

For the section shown in fig. 1 the coefficient K_1 describing the deviation from geometric acoustics can be deduced from ref. [3]:

$$K_1 = \frac{1}{2}\,[(C(v_1) + C(v_2))^2 + (S(v_1) + S(v_2))^2] \qquad (2)$$

where

$$v_1 = \sqrt{\frac{2}{\lambda}\left(\frac{1}{a_1} + \frac{1}{a_2}\right)}\cdot e\cdot\cos\Theta \;, \quad v_2 = \sqrt{\frac{2}{\lambda}\left(\frac{1}{a_1} + \frac{1}{a_2}\right)}\cdot(2b-e)\cdot\cos\Theta$$

λ is the wavelength and the other symbols are defined in fig. 1. C and S are the Fresnel integrals:

$$C(v) = \int_0^v \cos\left(\frac{\pi}{2}\,z^2\right)dz \;, \quad S(v) = \int_0^v \sin\left(\frac{\pi}{2}\,z^2\right)dz \;.$$

However, the general solution (2) is not easily used for practical applications.

3. Reflection at the centre of a surface

Considering the special condition $e = b$ it follows that $v_1 = v_2 = x$ and from (2):

$$K_{1,\text{centre}} = 2[C^2(x) + S^2(x)] \qquad (3)$$

where

$$x = 2b\,\cos\Theta/\sqrt{\lambda a^*} \qquad (4)$$

and the characteristic distance a^* is introduced:

$$a^* = 2a_1\,a_2/(a_1 + a_2) \;. \qquad (5)$$

The result (3) is shown graphically in fig. 2, and it appears that for low frequencies ($x < 0.7$) the diffraction gives rise to attenuation of the reflection. A very good and surprisingly simple approximation is:

$$K_{1,\text{centre}} \simeq 2x^2 \quad \text{for} \quad x \leq 0.7 \;. \qquad (6)$$

For higher frequencies some fluctuations appear due to the Fresnel zones. For very high frequencies these fluctuations decrease around the asymptotic value corresponding to an infinite surface: $K_{1,\text{centre}} \to 1$ for $x \to \infty$.

4. Reflection at the edge of a surface

Another special condition, $e = 0$, leads to $v_1 = 0$, $v_2 = 2x$ and from (2):

$$K_{1,\text{edge}} = \frac{1}{2}\,[C^2(2x) + S^2(2x)] \;. \qquad (7)$$

This result is very similar to that above, (3), and it is also shown in fig. 2. The approximations yield:

$$K_{1,\text{edge}} \simeq 2x^2 \quad \text{for} \quad x \leq 0.35 \qquad (8)$$

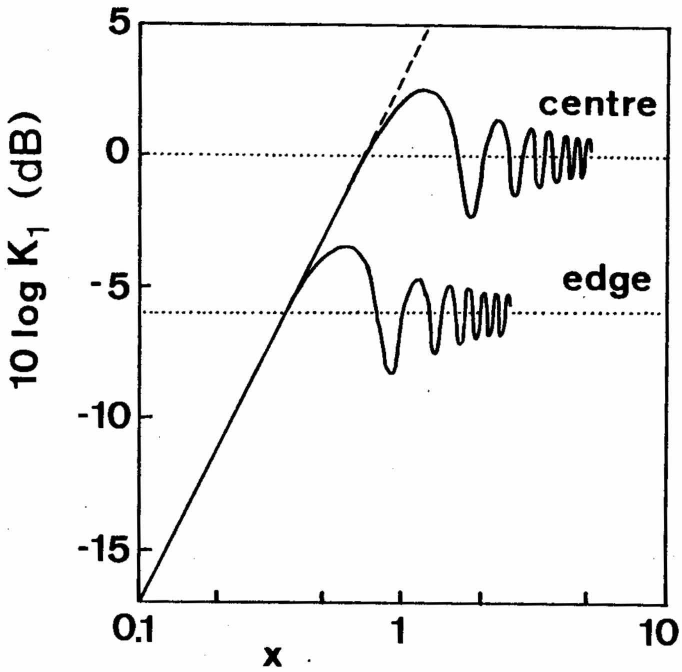
$$K_{1,\text{edge}} \to \frac{1}{4} \quad \text{for} \quad x \to \infty \;.$$

Thus, at high frequencies the reflection from the edge is attenuated about 6 dB relative to reflection from an infinite surface.

5. Approximations for practical use

Considering the sound reflection in general, the distance from the geometric point of reflection to the nearest edge is denoted by e, as shown in fig. 1. Depending on the value of x it is necessary to distinguish

Fig. 2 *Attenuation of reflection due to diffraction. Upper curve: Reflection at centre (3). Lower curve: Reflection at edge (7). Dashed line: Approximation for low frequencies (6) and (8).*



between three regions.

a) $x \le 0.35$: $K_1 \simeq 2x^2$, (9)

i.e. independent of the value of e.

b) $0.35 < x \le 0.7$:

$$K_1 \simeq \frac{1}{4} + (e/b)(2x^2 - \frac{1}{4}) \quad (10)$$

using linear interpolation between the approximate values.

c) $x > 0.7$: In this region the concept of an edge zone is introduced. A measure for the width of the edge zone is e_0:

$$e_0 = \frac{b}{\sqrt{2}\,x} = \frac{1}{\cos\Theta}\sqrt{\frac{1}{8}\lambda a^*}\ . \quad (11)$$

If $e > e_0$ the reflection can be treated geometrically with reasonable accuracy, but if $e < e_0$ the attenuation due to diffraction must be taken into account. Thus, the following approximations are suggested for $x > 0.7$:

$$K_1 \simeq \begin{cases} 1 & \text{for} \quad e \ge e_0 & (12a) \\ \frac{1}{4} + \frac{3e}{4e_0} & \text{for} \quad e < e_0\ . & (12b) \end{cases}$$

The simple approximations (9)-(12) have been compared with the more exact solution (2) for a number of values of x, and the agreement has been found to be good for practical use, see fig. 3.

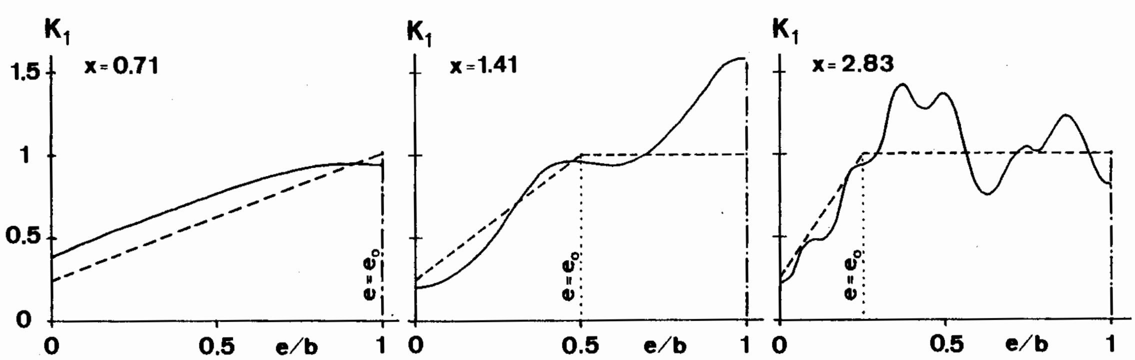


Fig. 3 *Calculated values of K_1 as a function of the distance e from the edge to the geometric point of reflection.* —— *: Exact (2),* - - *: Approximations (10)-(12).*

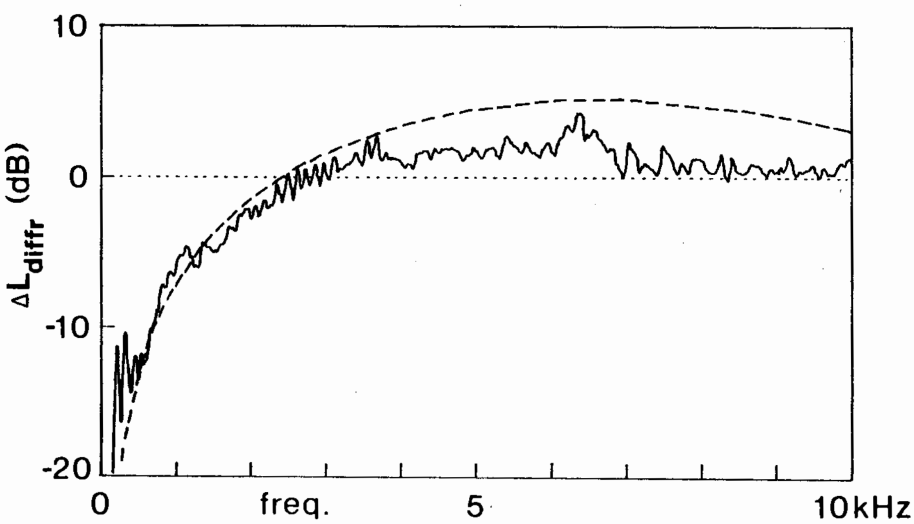


Fig. 4 *Measured and calculated attenuation of sound reflection from a square surface. ——— : Measured, - - : Calculated.*

6. Experimental results

Measurements of sound reflection were carried out in a large anechoic chamber using impulse gating technique and an FFT-analyzer B & K 2033. An example is shown in fig. 4. The measuring object was a 22 mm hardboard plate 0.60 m x 0.60 m. Distance to source a_1 = 6.00 m, distance to microphone a_2 = 4.00 m and angle of incidence $\Theta = 0^{o}$. The geometric point of reflection was at the centre of the surface. The attenuation of the sound reflection was found using a free-field measurement in the total distance $a_1 + a_2$ = 10.00 m as a reference.

In fig. 4 the measured attenuation is compared with the calculated attenuation due to diffraction using (1), (3), and the fact that $K_1 = K_2$ in this case. The results seem to be in good agreement, especially at lower frequencies. At higher frequencies the reinforcement is not so pronounced as expected from theory. This makes the proposed approximations even better.

7. Conclusion

The attenuation of a sound reflection from a hard surface with one or more free edges can be described by a special reflection coefficient due to diffraction. It has been shown that reflections near an edge can be treated easily by introducing an edge zone.

It follows from both theoretical and experimental results that the attenuation due to diffraction is of minor importance above a limiting frequency: $f > \frac{1}{2}ca^*/(2b \cos \Theta)^2$, corresponding to $x > 0.7$. It should be noted that the limiting frequency found here is one octave lower than the very often quoted result in ref. [4].

References

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