inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 7.6

PREDICTION OF NOISE PROPAGATION WITH ENERGY INTEGRAL EQUATIONS

K. Masuda

Taisei Technology Institute, Nase-cho 344-1, Totsuka-ku, 245-0051, Yokohama, Japan

Tel.: +81-45-814-7240 / Fax: +81-45-814-7256 / Email: kiyoshi.masuda@sakura.taisei.co.jp

Keywords:
ENERGY INTEGRAL EQUATION, NUMERICAL ANALYSIS, NOISE PROPAGATION, PREDICTION

ABSTRACT
A new method with energy integral equations for noise propagation prediction is developed. In the method all noise energy flows among boundary elements of a calculation model are obtained by solving simultaneous equations considering multiple reflection and diffraction. The new method realizes to make calculation process simple and is suited for the numerical analysis. In this paper the theory of the method and some calculation examples are introduced.

1 - INTRODUCTION
When the noise level in and around buildings is predicted, multiple reflection, multiple diffraction and their combinations must be taken into account. There are many factors causing multiple reflection and diffraction in and around buildings, e.g. shapes of rooms, arrangement of sound absorption materials, narrow spaces, and sound barriers. It is difficult to calculate the noise propagation phenomena by the sound lay method, because the order of reflection and diffraction increases exponentially. Though BEM and FEM have come to be used as calculation methods for noise propagation including multiple reflection and diffraction, the restriction of the element size against the wavelength is disadvantage of them, if noise energy distributes over the wide frequency range.
To solve the problems, a method of energy integral equations, which can deal with multiple reflection and diffraction, is developed. Comparing the calculation results by the method with ones by traditional methods, the efficiency of the new method is examined.

2 - ENERGY INTEGRAL EQUATIONS
In a sound field surrounded by boundary elements $\Delta S_n\,(n=1,,N)$ shown in Fig. 1, the rate of sound energy flow per unit area from a point $\mathbf{x}_j$ into a point $\mathbf{y}_k$ on the elements $I(\mathbf{x}_j,\mathbf{y}_k)$ can be calculated by the following integral equation,

$$I\left(\mathbf{x}_j,\ \mathbf{y}_k\right)=\sum_{i=1}^{N} I\left(\mathbf{y}_i,\mathbf{x}_j\right)\int\int_{\Delta S_i(\mathbf{y}')} R\left(\mathbf{y}',\mathbf{x}_j,\mathbf{y}_k\right)\frac{\cos\theta\text{co s}\theta'}{r^2}dS_i+\frac{QW}{4\pi r_s^2}R\left(\mathbf{x}_s,\mathbf{x}_j,\mathbf{y}_k\right)\cos\theta_s \qquad (1)$$

$\mathbf{x}_j$, $\mathbf{y}_i$ and $\mathbf{y}_k$ are the center points of the elements, and a uniform intensity at any points in each element is supposed. $R\left(\mathbf{y}',\mathbf{x}_j,\mathbf{y}_k\right)$ is the reflectivity coefficient [1] at the $\mathbf{x}_j$ and is given as

$$R\left(\mathbf{y}',\mathbf{x}_j,\mathbf{y}_k\right)=\left\{1-\alpha\left(j\right)\right\}\left[\frac{d\left(j\right)}{\pi}+2\left\{1-d\left(j\right)\right\}\delta\left(\theta_{in}-\theta_{out}\right)\delta\left(\varphi_{in}-\varphi_{out}\pm\pi\right)\right] \qquad (2)$$

where $\alpha\left(j\right)$ is the sound absorption coefficient of the element including the point $\mathbf{x}_j$ and $d(j)$ is the sound diffuse index, which is the ratio of random reflection energy following Lambert's law [2] in whole reflection energy. Here, it is supposed that the directivity of reflection is expressed as a linear combination of specular and random reflection. If a reflection is perfectly random then $d(j)$= 1. The specular reflection is expressed as $d(j)$= 0.

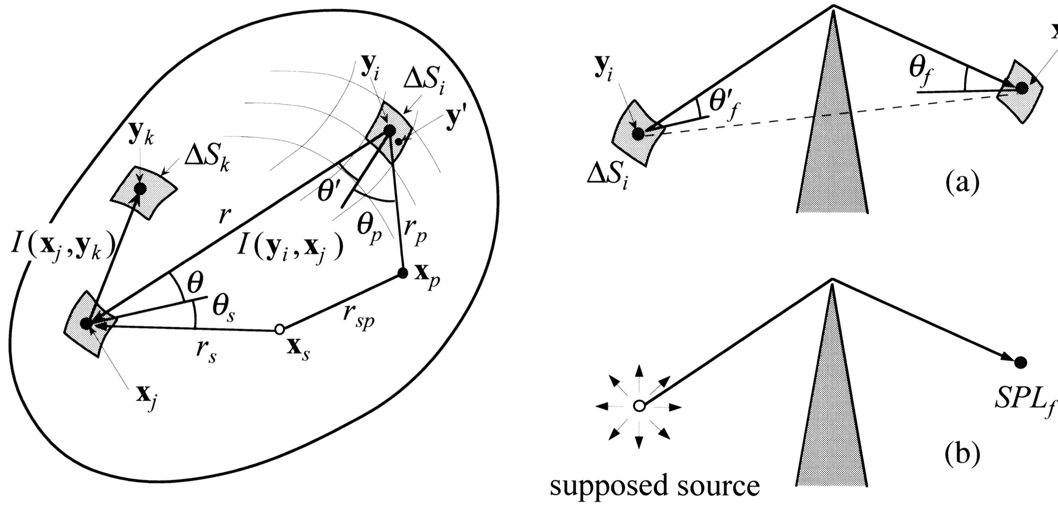

Figure 1: Geometry for the derivation of the equations and approximation of diffraction power flow.

The energy flow $I(\mathbf{x}_i,\mathbf{y}_j)$ approximates the energy flow from element ΔS_i to ΔS_j. Considering energy flow relations among all elements, we can obtain the energy integral equations. The solutions to these equations give all energy flows in the sound field, and substituting the solved $I(\mathbf{x}_j,\mathbf{y}_k)$ into

$$E\left(\mathbf{x}_p\right) = \sum_{i=1}^{N} I\left(\mathbf{y}_i, \mathbf{x}_p\right) \int\int_{\Delta S_i(\mathbf{y}_i)} \frac{\cos\theta_p}{r_p^2 c} dS_i + \frac{QW}{4\pi r_{sp}^2 c} \qquad (4)$$

the energy density $E(\mathbf{x}_p)$ at any points in the sound filed can be obtained.
If elements are between $\mathbf{y}_i$ and $\mathbf{x}_\mathrm{j}$ as shown in Fig. 1, the integral in the right side of Eq. (1) is replaced by

$$2R'\left(\mathbf{y}', \mathbf{x}_j, \mathbf{y}_k\right) \Delta S_i \cos\theta_f \cos\theta'_f 10^{(SPLf(i,j)-120)/10} \qquad (5)$$

Here, $SPL_f(i,j)$ is the sound pressure level of diffraction sound at $\mathbf{x}_j$ from a supposed multi-directional source at $\mathbf{y}_i$, which has the unit power. The calculation method of $SPL_f(i,j)$ is described in Ref. [3].

3 - CALCULATION MODEL

Noise propagation around two small model buildings on the ground was calculated by the new method (Fig. 2). There is a narrow space between the buildings, where multiple reflection may be occurred. A multi-directional sound source is put near the right side building. No direct sound carries to the opposite side of the buildings.
The boundary elements are set on the ground and the surfaces of the buildings. Here, the sound absorption coefficient of the ground is 0.3, and one of the building surfaces is 0.1. The sound diffuse index of all elements is 1.0. The shape of the element is square, whose dimensions are 1m by 1m. The total number of elements is 280. The analysis frequency is 500 Hz.
For comparison, the same condition was numerically analyzed by two traditional calculation methods for noise propagation. One is the method in which direct sound and multiple diffraction are calculated [4]. The other is what deals with direct sound and multiple reflection [5].

4 - CALCULATION RESULTS

The calculation results are shown in Fig. 3. The wide level differences among results of three methods are seen in the narrow space between the buildings and the opposite side of the buildings to the sound source. The reason of the differences is that the only the new method can take into account the following phenomena;

- incidence from the sound source to the narrow space including the diffraction
- less energy loss transmission through the narrow space
- sound radiation from the narrow space to the space behind the buildings including the diffraction

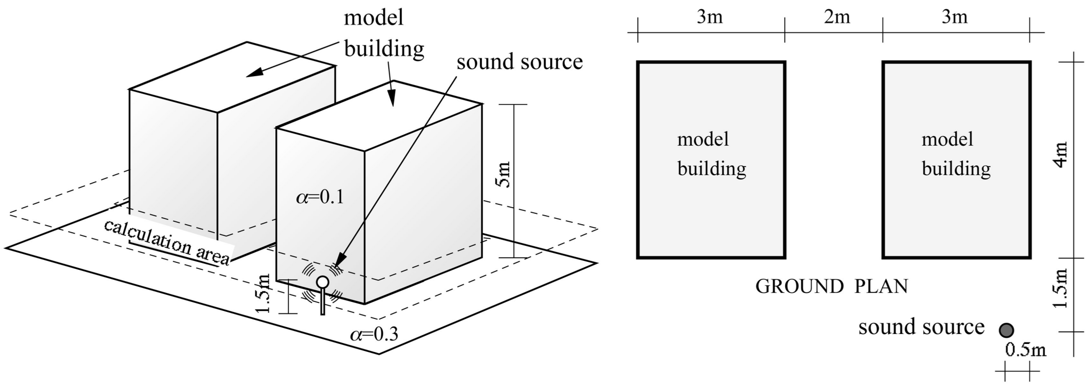

Figure 2: Calculation model and its dimensions.

The method (a) (direct and diffraction) can simulate the sound incidence to the narrow space, but the level decreases sharply because multiple reflection can not be calculated. The maximum level difference between the result of the new method (c) is about 10dB. This tendency agrees with the experimental results shown in Ref. [3].

The noise level distribution between buildings calculated by the method (b) (direct and reflection) is similar to one by the new method. It is clear that the multiple reflection in the narrow space influences the level to increase rather than multiple diffraction under the condition. In this case, an assumption that all elements are random reflection surfaces caused a similar effect to the diffraction. But it is insufficient, behind the buildings the level is about 5 dB lower than (c).

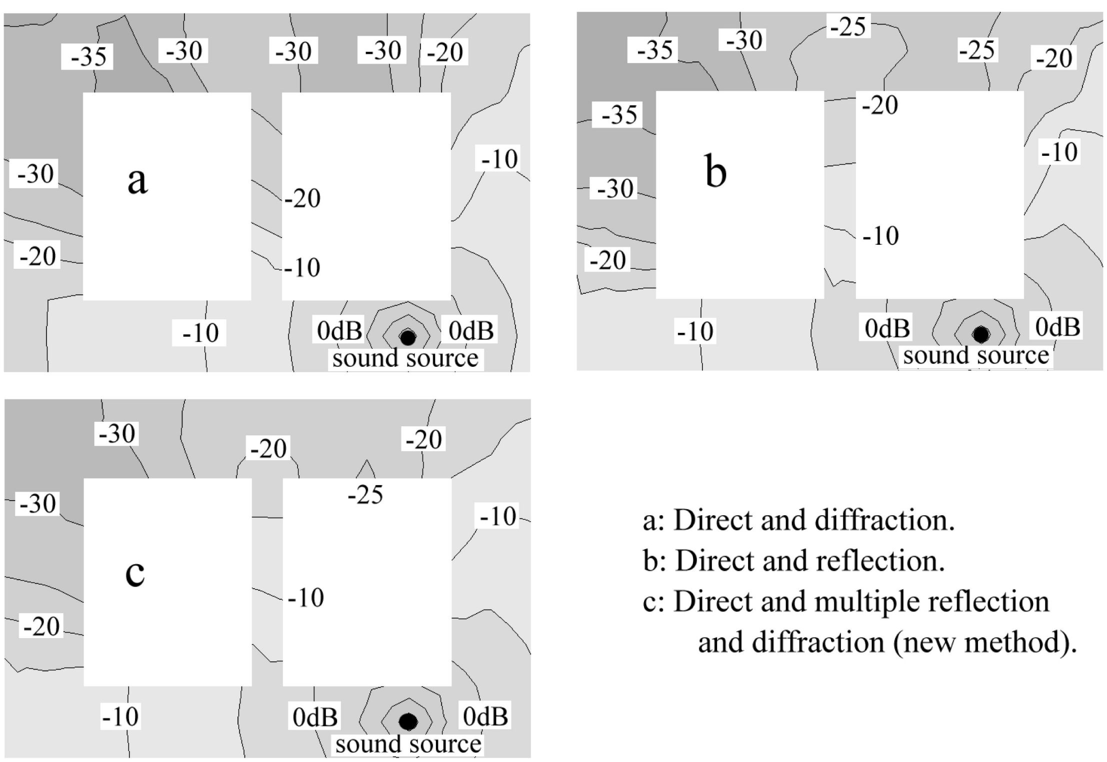

Figure 3: Calculation results by three methods.

5 - CONCLUSIONS

A new method with energy integral equations for noise propagation prediction is developed. In the method all noise energy flows among boundary elements of a calculation model are obtained by solving simultaneous equations considering multiple reflection and diffraction. Calculation results on sound propagation around model buildings show that the new method can simulate the noise propagation through narrow spaces influenced by multiple reflection and diffraction better than traditional methods.

REFERENCES

1. **W.B. Joyce**, Exact effect of surface roughness on the reverberation time of a uniformly absorbing spherical enclosure, *J. Acoust. Soc. Am.*, Vol. 64(5), pp. 1429-1436, 1978

2. **H. Kuttruff**, Simulierte Nachschallkurven in Rechteckraeumen mit diffusem Schallfeld, *Acustica*, Vol. 25, pp. 333-342, 1971

3. **K. Masuda**, Sound environment simulation system for prediction of noise propagation in and around buildings, In *ASVA97*, pp. 585-590, 1997

4. **M. Yuzawa**, Sound attenuation by multiple barriers, *Applied Acoustics*, Vol. 12, pp. 447-459, 1979

5. **R.N. Miles**, Sound field in a rectangular enclosure with diffusely reflecting boundaries, *Journal of Sound and Vibration*, Vol. 92(2), pp. 203-226, 1984