FMBEM ACOUSTIC SHAPE SENSITIVITY ANALYSIS AND ITS APPLICATION TO SHAPE OPTIMIZATION OF NOISE BARRIERS

Changjun Zheng, Haibo Chen[a)]
Department of Modern Mechanics, University of Science and Technology of China, Hefei, Anhui 230027, China

Summary A 3D BEM acoustic shape sensitivity analysis approach is proposed and applied to shape optimization of noise barriers. A very efficient half-space wideband fast multipole BEM is constructed. Constant element is used to discretize the boundary. In the shape optimization processes, a Y-type barrier is selected for optimization which leads to 3.3 dB deduction of the sound pressure level.

CONTENT

Nowadays, as the traffic noise pollution has become a very serious problem in the urban area, noise barriers which are the most effective method to mitigate the traffic noise have been widely applied. Since many factors can affect the acoustical performance of noise barriers, for instance, the material, location, dimensions and shapes, a large amount of research has been carried out in the last two decades to develop more efficient designs (Duhamel and Sergent [1], Fujiwara et al. [2], Ishizuka and Fujiwara [3], Duhamel [4], Wu and Wang [5]). However, most of these studies focus in 2-D simulations of sound diffraction around noise barriers, especially the predictions and comparisons of the performance of noise barriers with different shapes, but suffer from the lack of an optimization procedure to obtain more efficient shapes. Moreover, the 2D simulation is based on the assumptions of line sources and straight and infinitely long barriers, which may not be accurate in the practical applications in the urban area.

The present study proposes a 3D acoustic shape sensitivity analysis approach based on the boundary element method, and applies it to the shape optimization of noise barriers. The boundary element method is a very powerful alternative to the finite element method, especially in the external acoustic wave propagation problems, but it suffers from the high computational complexity and storage requirements. Therefore, the fast multipole method which was proposed by Greengard & Roklin [6] is employed in this study to accelerate the solution processes and also save the memory. Since the performance analysis of nose barriers is a typical semi-infinite problem, a very efficient half-space wideband fast multipole boundary element method is constructed. In the shape sensitivity analysis, the direct differentiation method is used to obtain the acoustic shape sensitivity coefficients, and the objective function is defined as

$$J = \frac{1}{2}(L - L_0)^2 \tag{1}$$

where L is the sound pressure level at the field point of interest, and L_0 is the design objective.

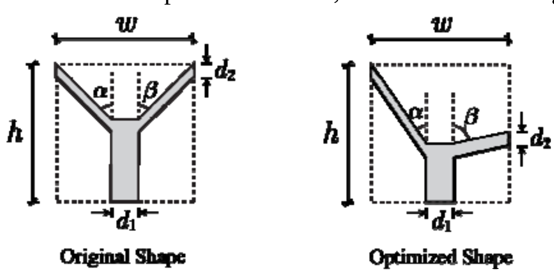

Figure 1: The original and optimized shapes of Y-type barrier

Moreover, in order to tackle the fictitious eigenfrequency problem of the original boundary integral equation method when solving external acoustic wave problems, the Burton-Miller approach (Burton & Miller [7]) is adopted in this study. Constant element is used to discretize the boundary so that the hypersingular boundary integrals in both the boundary state and sensitivity integral equations can be evaluated directly and efficiently without using any regularization technique (Zheng et al. [8]).

In the shape optimization processes, the acoustical performances of several typical noise barriers with different shapes are compared firstly, and then the Y-type barrier which has the best performance is selected for the further optimization study. The original and optimized shapes of the Y-type barrier are shown in Figure 1, the original shape with $\alpha = \beta = 45.0^\circ$, and the optimized shape with $\alpha = 35.4^\circ, \beta = 78.2^\circ$. After the optimization, the Y-type barrier has

a) Corresponding author. Email: hbchen@ustc.edu.cn.

another 3.3 dB deduction of the sound pressure level at nine selected points behind the barrier in comparison with the original one.

CONCLUSIONS

A 3D BEM acoustic shape sensitivity analysis approach is proposed and applied to shape optimization of noise barriers in this work. Numerical tests show the validity and efficiency of the proposed algorithm. This is the first research on 3D noise barrier shape optimization based on acoustic shape sensitivity analysis.

References

[1] Duhamel D., Sergent P.: Sound propagation over noise barriers with absorbing ground. *Journal of Sound and Vibration* **218**:799-823, 1998.
[2] Fujiwara K., Hothersall D.C., Kim C.: Noise barriers with reactive surfaces. *Applied Acoustics* **53**:255-272, 1998.
[3] Ishizuka T., Fujiwara K.: Performance of noise barriers with various edge shapes and acoustical conditions. *Applied Acoustics* **65**:125-141, 2004.
[4] Duhamel D.: Shape optimization of noise barriers using genetic algorithms. *Journal of Sound and Vibration* **297**:432-443, 2006.
[5] Wu C.H., Wang C.N.: A study of fast multipole method on the analysis of 2d barrier. *Journal of Mechanics* **25**: 233-240, 2009.
[6] Greengard L., Rokhlin V.: A fast algorithm for particle simulations. *Journal of Computational Physics* **73**:325-348, 1987.
[7] Burton A.J., Miller G.F.: The application of integral equation methods to the numerical solution of some exterior boundary-value problems. *Proc. Roy. Soc. Lond. A*. **323**:201-210, 1971.
[8] Zheng C.J., Matsumoto T., Takahashi T., Chen H.B.: Explicit evaluation of hypersingular boundary integral equations for acoustic sensitivity analysis based on direct differentiation method. *Engineering Analysis with Boundary Elements* **35**:1225-1235, 2011.