Noise scattering and shielding by roadside trees: results from a scale model

Hyung Suk JANG[1]; Jin Yong JEON[2]

[1,2] Department of architectural engineering, Hanyang University, Korea

ABSTRACT

Trees with randomized features of tree crowns, branches, and trunks produce various acoustical effects on the sound field and the noise propagation in urban areas. Acoustic measurements with 1:10 scaled trees were conducted to characterize the scattering and shielding effects on the pedestrian level and elevated locations. Properties of the tree models were altered to compare different configurations of trees: tree crown size, density of the foliage, and the gap between the arrays of trees. The scattered sound was captured below the tree crown and the decrement of sound pressure level behind the tree crown. Impulse responses and sound pressure levels were analyzed, and results showed that the noise levels in higher frequency bands were slightly increased at the pedestrian level. From the results of changes in the tree crown size and the density of foliage, the seasonal effects of trees on the acoustic environment can be discussed.

Keywords: Tree, Noise scattering, Scale model

I-INCE Classification of Subjects Number(s): 24.5, 52.3, 76.2

1. INTRODUCTION

Roadside trees are commonly encountered in streets and sidewalks in cities (1). The trees could increase the soundscape quality due to visual effects (2), and trees can also produce a higher perceived loudness of birdsongs by providing a shelter for the birds (3). As regards the acoustic properties of trees, the absorption coefficient of holly leaves was measured to be less than 0.1 in the frequency range of 100 Hz to 2.5 kHz, and that the scattering coefficient began to increase at 1 kHz (4). Even if a single leaf absorbs a small amount of sound energy, a tree, with its enormous number of leaves, could significantly attenuate noise (5). The scattering of tree scattering was studied in (6, 7) and the sound level was found to increase at positions below the trees and to decrease behind the tree crowns because the sound energy was scattered and reflected by the leaves and branches (6). Recently, noise mitigation by the various types of vegetation was evaluated using a 1:10 scale model (8). The scattering effects of roadside trees in the street canyon was also investigated, and the results showed that a tree crown increased the high-frequency sound pressure level. This work is the expanded study of the previous scale model measurement focusing on the tree scattering and shielding by roadside trees. The scattered reflections and the sound energy in the frequency domain were analyzed to understand the tree scattering.

2. Scale modeling

2.1 Selection of model trees

A tree model was constructed to investigate sound-scattering and acoustic shielding effects of trees at a 1:10 scale. The considered full scale tree was 7.7 m tall, and the diameter of the tree crown was 6.9 m. The tree was situated on grassland in an open field. The scale model tree was installed on a fitted glass material (10-mm-thick polyurethane) in an anechoic chamber to reproduce the conditions of the measurement of the full-size tree (9). A spark source and 1/8 inch microphones (B&K type 4138,

1 janghyungs@gmail.com
2 jyjeon@hanyang.ac.kr

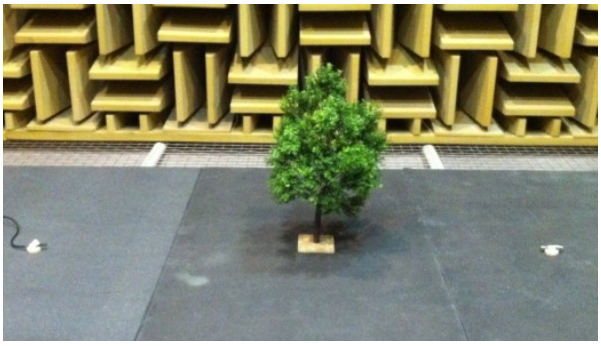

Figure 1 – A 1:10 scale model tree in an anechoic chamber

Denmark) were used to measure the impulse responses. At full scale, the sound source on one side was 10 m away from the tree, and IRs were recorded at 10 m from the tree. The source and the receiver were placed at the height of 0.5 m above the ground. The 1:10 model in the anechoic chamber is shown in Figure 1. The RTs for a real tree and a scale-model tree were compared, and showed a similar tendency for the frequency range 500 - 4000 Hz (8,9).

2.2 Construction of street scale model

European urban areas mainly consist of street canyons. A 1:10 scale model was constructed in a semi-anechoic chamber. The total length of the street canyon was 60 m (6 m in 1:10 scale). The buildings were 10 m tall for three floors, and the road between the façades was 9.2 m wide for two lanes. The structure of the scale model was made of 18-mm-thick unpainted MDF. It was assumed that rigid façades as hard surfaces consisted of bricks and windows. The ground surface in the street canyon was considered as a rigid surface made of asphalt (10). The typical installation of trees on both sides of the street was considered as shown in Figure 2. The twelve trees were installed on the edges of the sidewalk on both sides of the street at intervals of 9.6 m in a staggered pattern. The source height was 0.5 m, and the seven receiver positions were placed at the height of 1.5 m above the ground surface.

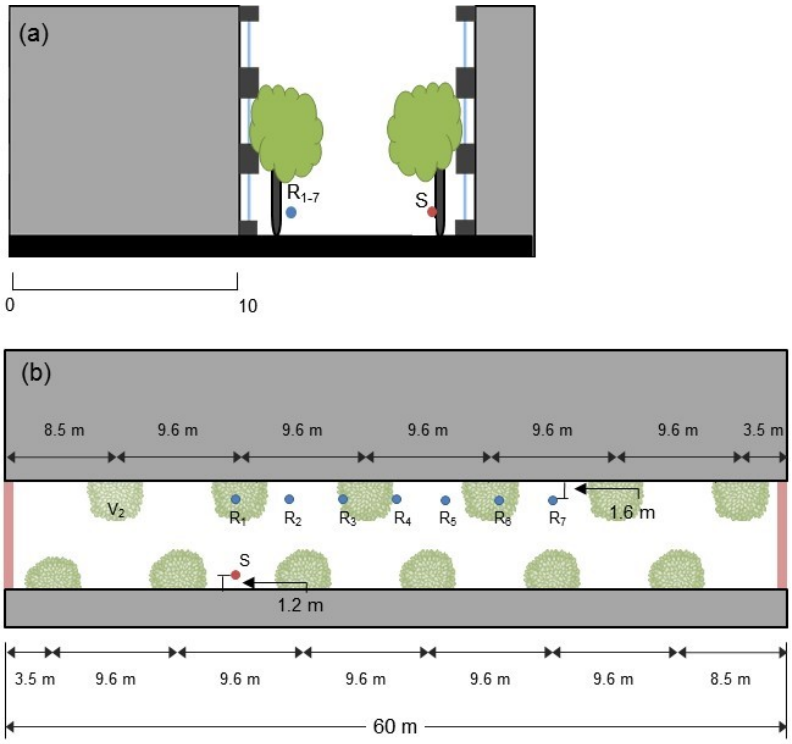

Figure 2 – (a) Section of street canyon with trees. (b) Plan view of roadside trees in the street canyon, and the source and receiver positions

2.3 Analysis methods

In this study, the impulse responses with and without trees were analyzed to find the effect of trees on the sound field of a street canyon. Jeon *et al.* (11) proposed a method to characterize the magnitude of diffusion by counting the number of peaks (*Np*) in broadband impulse responses (IRs). $N_{p,early}$ is defined as the number of reflected peaks in 80 ms, measured as sound levels within -20 dB from the direct sound. $N_{p,late}$ considers the range from 80 ms to 200 ms. Peaks that are local maxima in the IR are not reflections, but are arbitrary maxima in overlapping reflection components. The direct sound of a source signal contains some numbers of peaks as well. For the analysis of the effect of trees in outdoor spaces, the cut-off level from the direct sound was modified to -30 dB. The degree of sound diffusion can be defined as the number of peaks. The effects of scattering by trees were evaluated by investigating the IRs for a single tree and for trees in the street. The scattering effects by the trees were investigated by comparing the number of peaks in IRs of the case of trees and the case of empty ground.

In addition, the frequency responses of the IRs were analyzed to find the frequency bands affected by the tree scattering. The IRs were transformed in frequency domain by the a fast Fourier transform (FFT size equal to 512 samples of time signal) by using a Hanning window. The frequency responses of the measurements have been normalized with the same source to receiver distance in the empty anechoic chamber.

3. Results and discussion

3.1 A single tree in an anechoic chamber

Figure 3 shows the $N_{p,early}$ with and without a single tree on the ground in open field. The $N_{p,early}$ value from the IR without a tree was 24 peaks, and the $N_{p,early}$ value was increased by 49 peaks when the tree was placed on the ground. The results indicated that the tree produced sound scattering near the ground. The major difference in the time domain by the presence and absence of a tree in shown between 5 ms and 25 ms. The sound path between the source and receiver was 20 m, and the potential first reflections from the tree crown could be around 1 to 15 ms considering the bottom and the top of the tree crown. The starting point of the tree crown was at 2 m height from the ground. It may contain the scattered reflections or high order reflections with the ground as well. Figure 4 shows the frequency response of the presence and the absence of the tree. The results showed that the scattered energy was increased over 1000 Hz after installing trees.

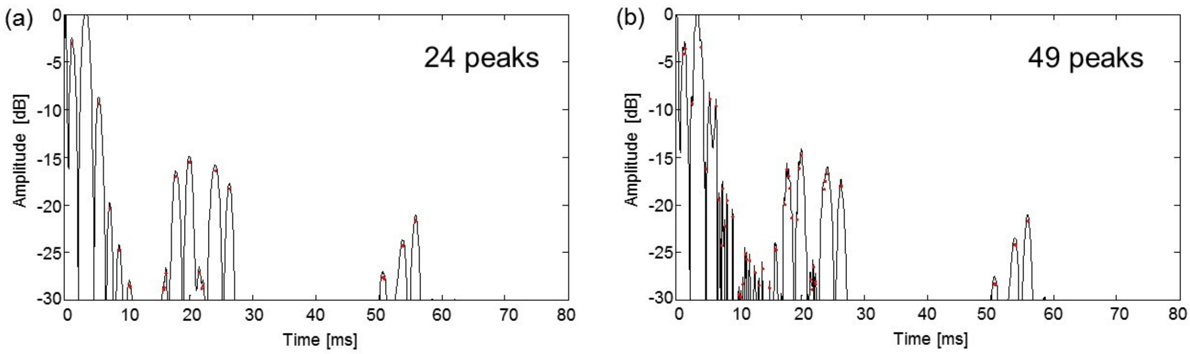

Figure 3 – Counting number of peaks ($N_{p,\,early}$) (a) without a tree assuming as open field, and (b) with a tree on the ground in an anechoic chamber. The IRs were converted to full scale.

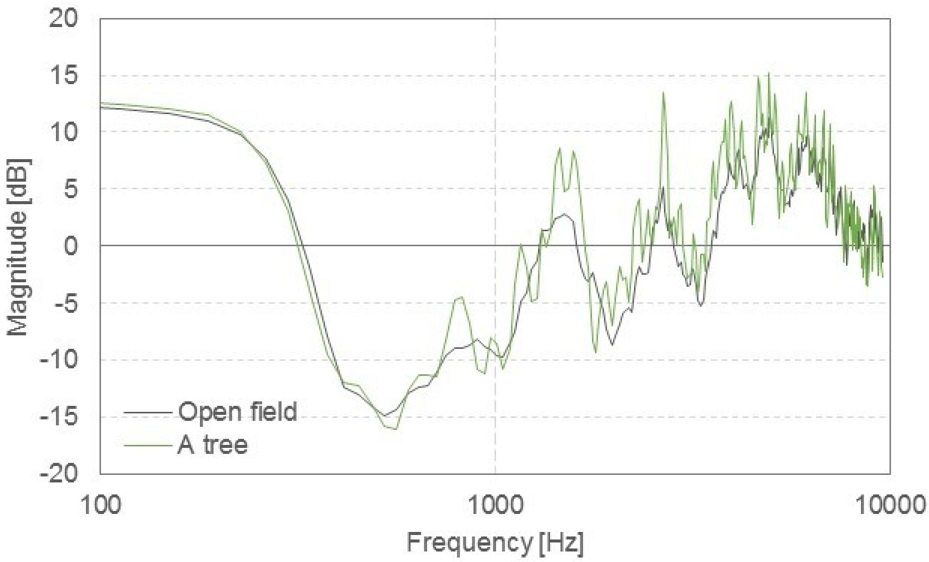

Figure 4 – Frequency responses of the case without a tree (Open field, Grey line), and with a tree (Green line)

3.2 Road-side trees in a street canyon

Two series of IRs were measured in the street canyon with and without trees. The temporal dispersion in the IRs indicates an increase in the number of peaks due to the scattered reflections from the trees in the street canyon. As shown in Table 1, $N_{p,early}$ and $N_{p,late}$ were calculated with and without trees at seven receiver positions. In all receiver positions, the N_p values increased about 50 peaks. The largest difference is shown in R1, as the trees decreased the flutter echo from the parallel walls as shown in Figure 2(a) and produced the scattered reflections from the below the tree crown. Figure 5 shows the frequency response of the presence and the absence of the tree in R1. The result showed that the scattered energy was increased over about 1500 Hz after installing trees.

Table 1 – Counting number of peaks ($N_{p,\ early}$) (a) without a tree assuming as open field, and (b) with a tree on the ground in an anechoic chamber

	$N_{p,early}$			$N_{p,late}$		
	Rigid façades	with trees	ΔN_p	Rigid façades	with trees	ΔN_p
R1	160	236	76	112	180	68
R2	182	236	54	113	204	91
R3	195	251	56	161	189	28
R4	218	246	28	205	256	51
R5	190	252	62	204	247	43
R6	186	237	51	228	254	26
R7	187	233	46	207	261	54
Average	188.3	241.6	53.3	175.7	227.3	51.6

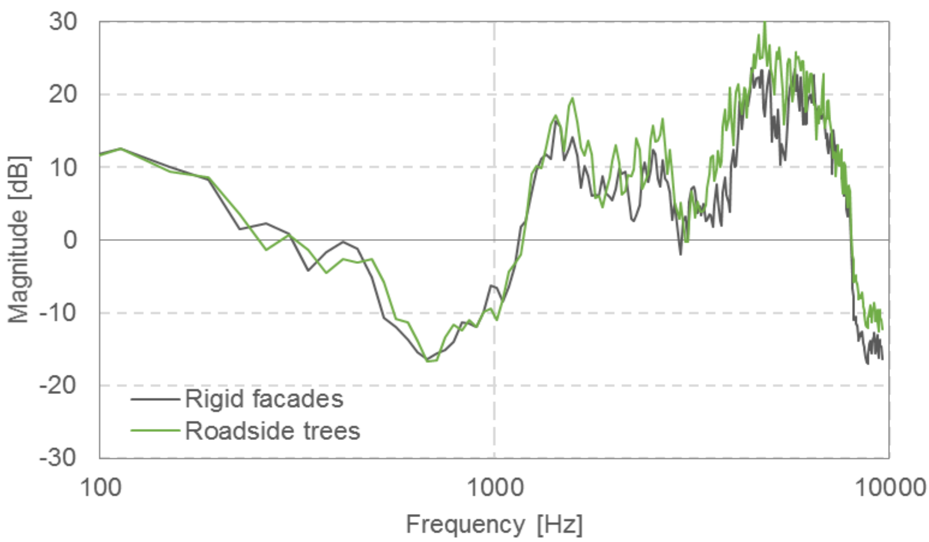

Figure 5 – Frequency responses of the case without a tree (Rigid façades, Grey line), and with roadside trees (Green line) in R1

4. CONCLUSIONS

This study focused on the sound scattering by the trees using a 1:10 scale model. In an open field, and in a street canyon, an increased number of peaks in the impulse responses of early part (0 ms to 90 ms) by the trees were found, and the scattered energies are mainly above 1000 Hz. It also found that the late number of peaks from 80 ms to 200 ms was increased by the trees in the street canyon. Installing trees in a street canyon could negatively affect noise abatement at frequencies over 1 kHz at a pedestrian's ear level owing to the diffusion by the leaves and branches. In future work, the different configurations of the trees shapes will be considered to find the dominant factors affecting the noise level. Moreover, different locations of receivers need to be considered further.

REFERENCES

1. Tang SH, Ong PP. A Monte Carlo technique to determine the effectiveness of roadside trees for containing traffic noise. Appl Acoust. 1988;23(4):263–71.
2. Hong J, Jeon J. Designing sound and visual components for enhancement of urban soundscapes. J Acoust Soc Am. 2013;134(3):2026–36.
3. Liu J, Kang J, Behm H. Birdsong as an element of the urban sound environment: A case study concerning the area of Warnemünde in Germany. Acta Acust united with Acust. 2014;100(3):458–66.
4. Yang H, Kang J, Cheal C. Random-Incidence Absorption and Scattering Coefficients of Vegetation. Acta Acust united with Acust. 2013;99:379–88.
5. Martens M, Michelsen A. Absorption of acoustic energy by plant leaves. J Acoust Soc Am. 1981;69(1):303–6.
6. Lyon R, Blair C, DeJong R. Evaluating effects of vegetation on the acoustical environment by physical scale-modeling. Proceedings of the Conference on Metropolitan Physical Environment. 1977. p. 218–25.
7. Hornikx M, Botteldooren D, Van Renterghem T, Forssén J. Modelling of scattering of sound from trees by the PSTD method. In Proc. of Forum Acusticum, 27 June - 1 July, Aalborg, Denmark, 2011.
8. Jang HS, Lee SC, Jeon JY, Kang J. Evaluation of road traffic noise abatement by vegetation treatment in a 1:10 urban scale model. J Acoust Soc Am. 2015;138(6).
9. Yang H-S, Kang J, Cheal C, Van Renterghem T, Botteldooren D. Quantifying scattered sound energy from a single tree by means of reverberation time. J Acoust Soc Am. 2013;134(1):264–74.
10. Jang HS, Kim HJ, Jeon JY. Scale-model method for measuring noise reduction in residential buildings by vegetation. Build Environ. 2015;86:81–8.
11. Jeon JY, Jang HS, Kim YH, Vorlander M. Influence of wall scattering on the early fine structures of measured room impulse responses. J Acoust Soc Am. 2015;137(2013):1108–16.