Analysis of Air Current Flow around Noise Barrier on Expressways Using the PIV Technique

Jang-Youl You, Hyeon-Ku Park, Young-Moon Kim and Ki-Pyo You

ABSTRACT

Urbanization has resulted in the extension of road networks and development of belt ways due to the expansion of cities and overpopulation. With the expansion of cities, resident population started to live nearby roads and is experiencing issues like spreading of air pollutants and noises generated on roads. In general, such issues are prevented by installing noise barrier and windproof walls on roadsides, which have great impact on reduction of noises and air pollutants. Previous studies about the effects of noise barrier and windproof walls on movement of pollutants were mostly conducted as partial field experiments and numerical experiments using computational fluid dynamics (CFD). Therefore, there is lack of studies on movement of wind and its effects. The purpose of this study is to examine form of actual wind based on noise barrier and the effects of wind on residents through particle image velocimetry (PIV).

INTRODUCTION

In recent decades, the development of road networks and urban ring roads has increased significantly in line with urban expansion and population overcrowding. As urban expansion continues, more residents are living in the vicinity of roads than before, and this is leading to more pollutants from roads and increased noise pollution. Thus, it is important to understand the effect of these problems as a social issue. Since noise and air pollutants proliferate in residential areas, external road traffic noise and the transmission of air pollutants are causing considerable damage. To address this problem, sound-absorbing or windbreak walls are being installed at the sides of roads and are having a significant effect on the reduction of noise and air pollutants. However, as such measures are a relatively new phenomenon, it is necessary to study the effect on the immediate environment of pollutants emitted

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from the road and dispersed by the wind. A sound-absorbing wall can initially cause a bigger mixture of pollutants through increased turbulence around the wall structures and initial blockage of the spreading pollutants (bad odors or dust, etc.). The wall may also increase the surrounding pollution source concentration by stagnating the movement of the pollutants. Windbreak walls affect the concentrations around the structure by blocking the initial proliferation of the various pollutants emitted from roads. To date, most studies on pollutant movement due to noise barrier and windbreak fences have focused on partial site experiments and numerical experiments carried out using computational fluid dynamics (CFD). In addition, a number of experimental studies on the flows surrounding windbreak fences have been conducted. Raine and Stevenson measured the mean velocity of back-flow in a windbreak fence, and root mean square (RMS) perturbation velocity using a hot wire flow velocimeter, while Perera performed a study on flows around various porous fence types by creating an atmosphere layer in a wind tunnel experiment. Furthermore, after carrying out wind tunnel experiments on porous fences, Kim et al. in Korea verified that the reduction in wind speed was greatest when the porosity of the fence was 40%. Through a CFD analysis, Jeong also determined that the concentration around the ground at the lower air stream in the windbreak wall was reduced by 1.0 to 1.1 when the height of the sound-absorbing wall was increased more than just a single windbreak wall was installed. However, few studies have been conducted on the effect of wind and wind movement type. In this study, the shape of the wind due to the sound-absorbing wall and the effect of the wind on residents were analyzed through particle image velocimetry (PIV).

**PIV EXPERIMENT**

For the purposes of this research, a wind tunnel experiment was conducted to analyze air currents using PIV. The model scale used in the wind tunnel experiment was a 1/100 ground model. In order to determine the wind speed flow before and after installation of the sound-absorbing wall, PIV was used to experiment with and analyze wind velocity distribution and shape. Regarding the shape of the sound-absorbing wall, the most widely used types were selected for the experiment, namely, the vertical wall type (16 m) and the arch wall type (11.4 m). The measurement area was divided into two sections on the sound-absorbing wall, Section A and Section B, and the air current flow occurring at the two sections was analyzed. For each section, 250 captures of images were acquired so that a mean velocity field could be obtained. The study area was 64 pixels x 64 pixels, and cross-correlation was also conducted. The experiment was carried out at the Large Wind Tunnel Test Center in Chonbuk National University, and the wind velocity field was evaluated according to whether or not a sound-absorbing wall was present at a 1 m/s velocity condition in a direction vertical to the sound-absorbing wall. Photo 1 shows the PIV measurement area.
The basic principle of PIV involves a flux measurement method used to track particles scattering in a laser light sheet, as shown in Fig. 1, so that a velocity field at the plane can be obtained. The basic configuration of the PIV system consists of a laser, optics that produce a light sheet, a camera that acquires images, and a synchronizer that synchronizes those images.

Particle displacement in two images acquired using the PIV system is measured using a cross-correlation technique in the interrogation region, which determines a direction for the displacement of the two images. Each displacement is expressed via pulse interval time $t$ of the laser; in this way, the displacement/time or velocity at each interrogation region can be obtained. Fig. 3 is a schematic diagram of the cross-correlation process. Table 1 shows the specification of the PIV system and Photo 2 shows the measured data.
TABLE 1. SPECIFICATION OF THE PIV SYSTEM.

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<td>1)</td>
<td>200mJ, 15Hz Dual head Nd-Yag laser.</td>
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<tr>
<td>2)</td>
<td>2048*2048 resolution 4MP Camera</td>
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<td>3)</td>
<td>1ns resolution Synchronizer</td>
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<td>4)</td>
<td>Single nozzle oil droplet generator</td>
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<td>5)</td>
<td>Insight 3G software</td>
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MEASUREMENT RESULTS

Fig. 4 shows the PIV measurement image before and after the installation of the sound-absorbing wall and the analysis image after post-processing using a computer. The analysis result shows that no significant change in air current was found in the upper area of the two measurement locations, Sections A and B, in the wind-blowing direction prior to the installation of the sound-absorbing wall. However, the air current moved constantly in the lower area of Section A, whereas there was a considerable reduction in wind velocity because one embankment slope was steep at the lower air current on the rear side of the sound-absorbing wall in Section B. The wind velocity at the upper area of Section A was 0.8 m/s and it was 0.4 m/s at the bottom area of the embankment, which was the lower part. The wind velocity at the upper area of Section B was 0.6 m/s and it was 0.2 m/s at the lower area. Fig. 5 shows the measured image and the analyzed image when a vertical sound-absorbing wall type was installed. Following the installation, both Section A and Section B showed reduced wind velocities at the upper and lower areas. In Section A, a reduction of about 75% in the wind velocity effect at the upper part was found at the rear side of the sound-absorbing wall compared to before the installation of the wall. Wind velocity in the lower part was reduced by about 50%. In Section B, a reduction effect of about 83% in the upper part’s wind velocity was found at the rear side of the sound-absorbing wall compared to before the installation of the sound-absorbing wall, while the lower part’s wind velocity was reduced by about 50%. The wake phenomenon occurred at the air current in the vertical sound-absorbing wall. Specifically, in Section A, the wake phenomenon occurred in the upper area, which was 10 cm away from the sound-absorbing wall, and in Section B, it occurred in the
upper area, which was 30 cm away from the sound-absorbing wall. In fact, the wake phenomenon occurred at the height of the upper part of the sound-absorbing wall. Fig. 6 shows the measured image and the analyzed image when an arch type sound-absorbing wall was installed. In the case of this installation, Sections A and B had reduced wind velocities at both the upper and lower areas in the same way as the vertical wall type. In Section A, a reduction effect of about 50% in the upper part’s wind velocity was found at the rear side of the sound-absorbing wall compared to before the wall’s installation. Conversely, the lower part’s wind velocity was nearly the same as without the sound-absorbing wall. In Section B, a reduction effect of about 50% in the upper part’s wind velocity was found at the rear side of the sound-absorbing wall compared to before the installation of the wall, while the lower part’s wind velocity was nearly the same as without the sound-absorbing wall. The wake phenomenon did not occur in the air current of the arch sound-absorbing wall type; this was in contrast with the vertical sound-absorbing wall type.

Figure 4. Measured and analyzed images before and after the installation of the noise barrier.
CONCLUSIONS

Recently, a number of noise barriers and tunnels have been installed in apartments and residential areas around expressways. However, these facilities have affected ventilation in the surrounding areas. Therefore, the aim of this study was to perform PIV experiments to offer an understanding of changes in air currents before and after the installation of noise barrier (arch wall type and vertical wall type) around expressways. The following conclusions were drawn from the study:

1. The upper air current was in constant motion if a sound-absorbing wall was not installed at the expressway, but at the lower part of the wall, wind velocity was reduced due to the embankment’s effect on the expressway. The embankment part of the expressway construction was found to affect the surrounding air current as well.
2. The PIV experiment result, which aimed to clarify the effect of air currents on the immediate environment due to the installation of a sound-absorbing wall on the expressway, showed that when a vertical type sound-absorbing wall was installed, wind velocity was reduced in Section A by 50% to become 75% of velocity compared to the percentage values in the absence of a sound-absorbing wall. In Section B, the reduction effect was 83% to 50%. The wake phenomenon occurred at 10 cm away from the vertical sound-absorbing wall type in Section A and at 30 cm away from the vertical sound-absorbing wall type in Section B.

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REFERENCES


