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Determination of Design Wind Loads on a Free Standing Wall Considering Climate Change

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ABSTRACT

Effects of aerodynamic modifications of the noise barrier with various leading edges were investigated by wind tunnel tests. Five types of noise barriers were considered in this study. Also, relationship between the return period and design wind speed were discussed to determine reasonable wind loads on the noise barrier. As a result, mean net force coefficients on the noise barrier with square leading edge (case 1) were good agreement with those of ASCE 7-10. Further leading edge of case 4 were most effective in reducing the mean net force coefficients. These results can be useful for improvement in wind loading codes related in structural design of the free standing walls.

1. INTRODUCTION

Noise barriers (generally referred to as free standing walls) have been installed to reduce the road traffic-generated noise and these have been developed in a way of changing soundproof materials. The height and length of noise barriers has been higher and longer in a bid to improve the noise reduction effects. Further, the noise barriers along freeways or motorways, and hoardings have may be of lesser economic importance, but are often sensitive to wind loads, fail early during a strong wind and provide a source of flying debris. Wind loads on noise barriers have been studied by some researchers through wind tunnel tests and full scale tests (Geurts, and Bentum 2010; Holmes 2000; Letchford and Holmes 1994; Letchford and Robertson 1999; Robertson et al., 1997). These studies found significantly increased wind load on panels adjacent to free ends of such walls. To reduce wind loads on free standing walls,

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Letchford and Holmes (1994) suggested the return corner of the free standing wall, and found the fact that there was a significant reduction in net mean pressure coefficients at the wind direction of 45 degrees, while significant increased the net mean pressure coefficient on free standing walls without the return corner. There results have been codified for design in ASCE 7-10 and Eurocode 1. However, there are restrictions on practical application in the aspects of securing the installation space, since the return corner is installed in direction perpendicular to the free standing wall.

In this study, to suggest generalized net force coefficient on the noise barriers, effects of aerodynamic modifications of noise barriers with leading edges of various forms are investigated and presented. In addition, the return periods for design wind speed are discussed to determine reasonable wind loads on the noise barrier.

2. DESIGN VELOCITY AND RETURN PERIOD

Net wind force coefficients on a noise barrier fall into two categories corresponding to the design of the structural frames and claddings. The design wind load on the noise barrier in Korean Building Code and Commentary, 2016 (KBC 2016) can be defined by Eq. (1).

$$W_s = q_H G_F C_F A \tag{1}$$

where, W_s, q_H, G_F, C_F and A are design wind load on a noise barrier, design velocity pressure, gust effect factor, net wind force coefficient and projected area, respectively. Here, design velocity pressure is converted to the design wind velocity as shown in Eq. (2).

$$q_H = 1/2\rho V_0 K_{zr} K_{zt} I_w \tag{2}$$

where, ρ, V_0, K_{zr}, K_{zt} and I_w are air density, basic wind speed, wind speed profile factor, topographic factor and important factor, respectively.

The basic wind speed is based on mean wind measurements at 10 m height in an open terrain with 100-year return period. However, the lifetime of the noise barrier may be short compared to that of normal buildings because maintenance for the noise barrier is more difficult due to being exposed with vulnerable environment. In economy point of view, when designing the structural frames and cladding of a noise barrier, it may be uneconomical to use in frame design with 100-year return period wind speed. Thus, one of the issue is that how long a return period of the basic wind speed should be used in design of the noise barrier frames. Exceedance probability (P_t) of a wind speed over the lifetime can be determined by assuming that all years are statistically independent of each other as shown in Eq. (3).

$$P_t = 1 - \left(1 - \frac{1}{r}\right)^t \tag{3}$$

Assuming 20-year lifetime of the noise barrier, relationship between exceedance probability and return period is as shown in Table 1. It means that there is nearly 64% and 33% chance that the 50-year return period wind speed will be exceeded at least once during a 20-year and 50-year lifetime, respectively. Thus, the design wind loads derived from wind speeds with this exceedance probability should be considered when used for ultimate limit state design. Typical values of wind load factor are in the range of 1.4 and 1.6. It should be noted that the use of a return period for design wind velocity substantially higher than the 20-year, but it still remains that which return periods have to be used in the design of the structural frame of the noise barrier. The wind load factor is required for regions with different wind speed and return period relationship.

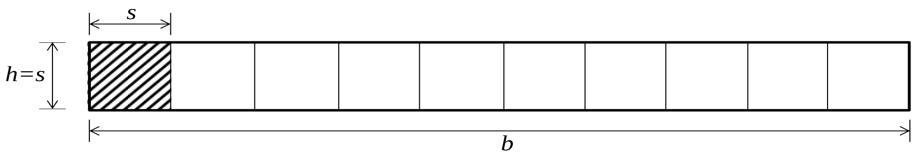
Table 1. Relationship between exceedance probability and return period for 20-year lifetime of noise barrier

Return period (r)	20-year	50-year	100-year	500-year	1000-year
Exceedance probability (P_t)	64%	33%	18%	4%	2%

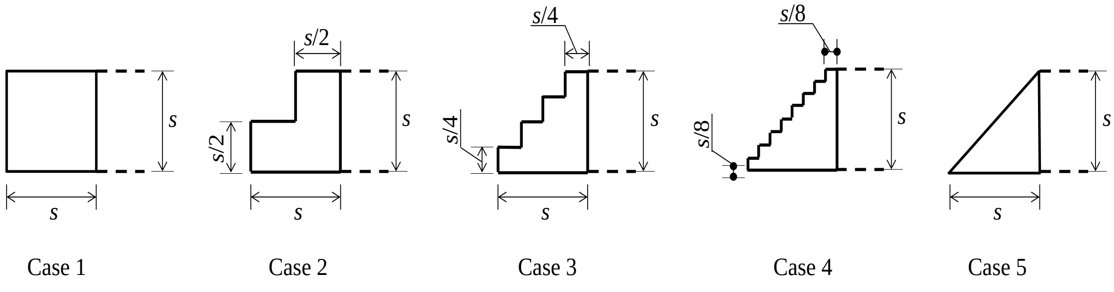
3. WIND TUNNEL TESTS

The high-frequency pressure measurement tests were carried out the boundary layer wind tunnel at Wind Engineering Research Center, Tokyo Polytechnic University, Japan. The test section of the wind tunnel is 2.2m wide, 1.8m high and 19m length.

The prototype of the test model is determined by results of Heo et al., (2002). The dimension is 100m length and 10m height. In this study, five types of the test models were considered as shown in Fig. 1. Wind directions will be considered from 0° to 45° in 5° steps. In this paper, it was only discussed with results for wind direction 0°. The Fig. 2 shows the test models installed in wind tunnel.



(a) Elevation view



(b) Teest model caes

Fig. 1 Configuration of test models

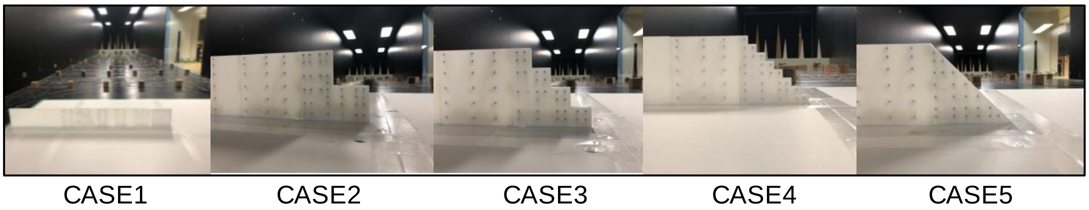
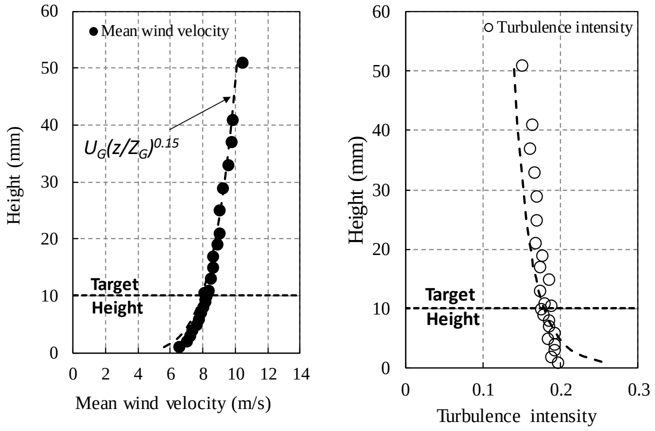


Fig. 2 Test models installed in wind tunnel



(a) Mean wind velocity (b) Turbulence intensity

Fig. 3 Mean wind velocity and turbulence intensity profiles

The approach flow represents an agricultural field region using spire-roughness technique with a power law exponent of 0.15 as shown in Fig. 3. The mean wind velocity and turbulence intensity at model height was 8.1 m/s and 18.5%, respectively. A time history of pressure for each sample is corresponding to 15 samples of 10-min length in full scale conversion. Pressure taps were installed on the windward and leeward walls of test models. The fluctuating wind pressures on the test models were simultaneously measured at all pressure taps. The pressure records were digitally filtered low-pass filter with 300 Hz. The tubing effects were numerically compensated by the gain and phase-shift characteristics of the pressure measuring system (Irwin et al., 1979; Kim et al., 2011). Net local force coefficient on the test model can be calculated by Eq. (4).

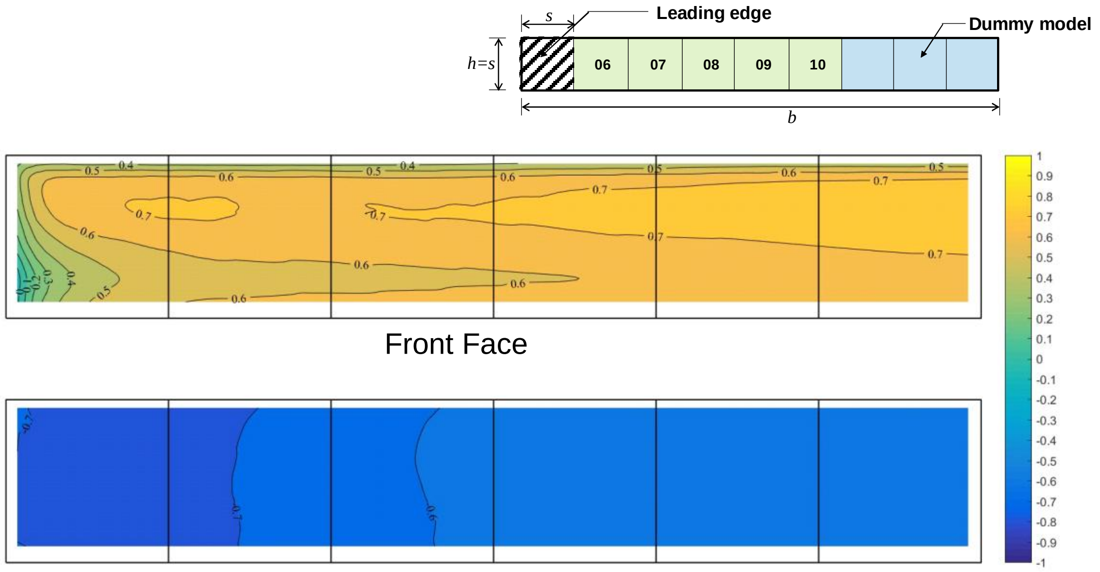
$$C_n(i,t) = C_{pw}(i,t) - C_{pl}(i,t) \tag{4}$$

where, $C_{pw}(i,t)$ and $C_{pl}(i,t)$ are wind pressure coefficients at measurement tap i at time t on the windward and leeward surfaces of the test model, respectively, and $C_n(i,t)$ is the net local force coefficient at measurement tap i and time t.

3. RESULTS AND DISCUSSION

Fig. 4 shows mean wind pressure coefficient on the noise barrios of case 1. In Fig. 4, the maximum value of mean pressure coefficients on the front wall of case 1 was observed at about 0.8h which is stagnation point. On the other hand, the value of mean wind pressure coefficients on the leeward wall of the case 1 were almost no change. These results are good agreement with those of typical rectangular structures.

Fig. 5 shows mean net force coefficients on case 1 with different aspect ratios (*b*/*s*). These results were compared with those of the ASCE 7-10. As shown in Fig. 5, it is clear that mean C_N for case 1 were decreased with increase in aspect ratios. These results were good agreement with those of the ASCE 7-10.



Front Face

Back Face

Fig. 4 Distribution of mean wind pressure coefficients on noise barrier

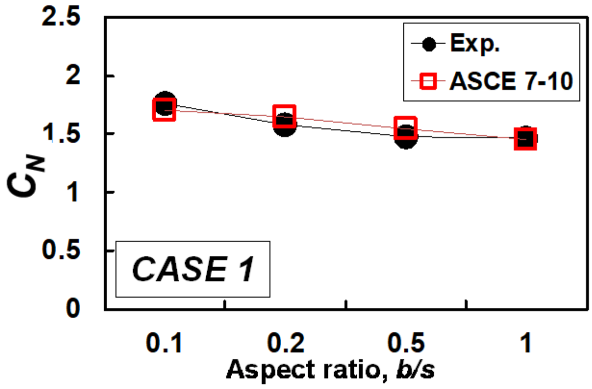


Fig. 5 Net force coefficients on noise barrier (case 1) with different aspect ratios

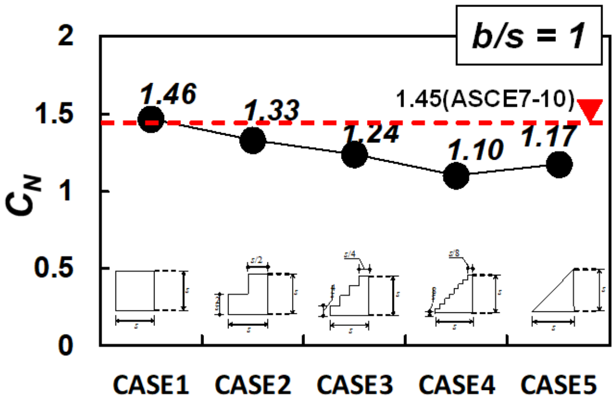


Fig. 6 Net force coefficient on noise barriers with various leading edges when the aspect ratio is 1.

Fig. 6 presents mean C_N for the noise barrier with various leading edges when the aspect ratio is 1. Notable observation was that the most of noise barriers with various leading edges show better aerodynamic behaviors in mean C_N compared with that of case 1. Particularly, mean C_N for case 4 were most effective in reducing the mean net force coefficients, and about 25% in mean C_N was reduced compared with that of case 1. On the other hand, mean $C_{N\ for}$ case 5 was slightly increased from that of the case 4. It implies that there is aerodynamically no effect for change from the stepped leading edge (case 4) to inclined leading edge (case 5) of the noise barrier.

4. CONCLUSIONS

Effects of aerodynamic modifications of the noise barrier with various leading edges (5 types) were investigated in this study. As a results, mean net force coefficients on the noise barrier with square leading edge were good agreement with those of ASCE 7-10. Further leading edge of case 4 were most effective in reducing the mean net force coefficients. These results can be useful for improvement in wind loading codes related in structural design of the free standing walls. However, it will be necessary to proceed with a more detailed analysis to estimate net forces to use the practical design of noise barriers.

ACKNOWLEDGEMENT

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