Aerodynamics of the Highway Sign Support Structure: Experimental Investigation of The Sign Geometry Effects

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ABSTRACT

Highway signs have been commonly used to communicate with the drivers. Multiple types of structures have been used to support these signs, such as pole type, cantilever type and gantry type. In this study, the effects of the sign geometry on the aerodynamic force coefficients of the pole type supporting structure have been investigated experimentally. Multiple parameters of the sign geometry, such as the sign size (area) and sign aspect ratio, have been studied. Furthermore, two cross-sectional shapes of the pole, namely square and dodecagon, have been adopted in this study to investigate the effect of the pole shape on the aerodynamic force coefficients of the supporting structure. The results showed that negative aerodynamic coefficients are generated due to the flow separation and reattachment near the sharp corner of the pole with a square section. For the same aspect ratio, as the sign size increases, the aerodynamic coefficients increase when the flow angle ranges 45 - 75 degrees.

1. Introduction

Highway signs have been commonly used to communicate with the drivers. To ensure the visibility of these signs, multiple types of supporting structures have been used, such as pole type, cantilever type and gantry type, as shown in Figure 1. Multiple factors are being involved in the selection of the supporting structure type, such as the road geometry (number of lanes, width of each lane and one-way or two-way road) as well as the road limitations (the presence of a neighbouring buildings).

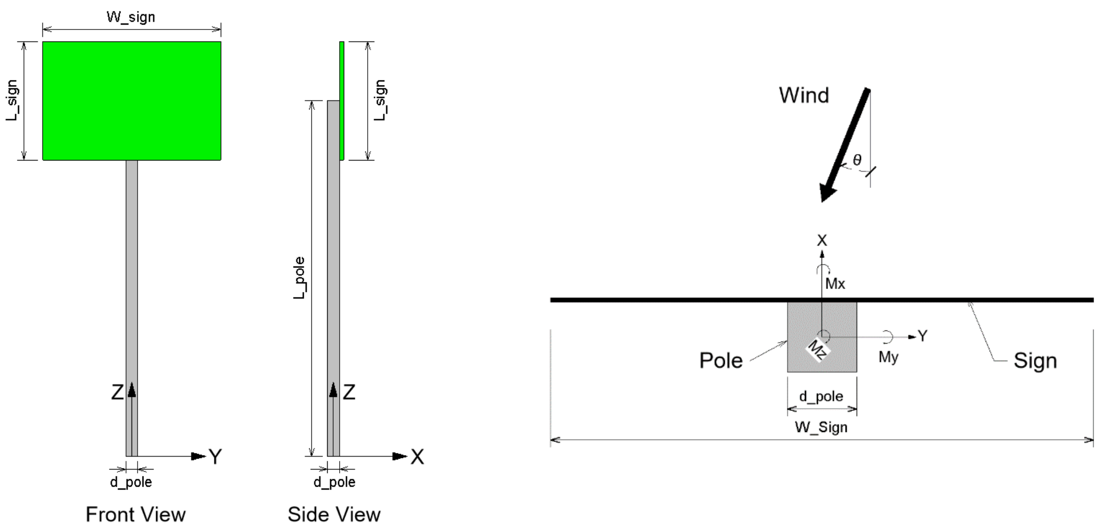
(a) (b) (c)

Figure 1. Highway sign supporting structures (a) Pole type (b) Cantilever type (c) Gantry type

Highway sign supporting structures are subjected to significant wind loads. As a result, understanding the behavior of these structures under the wind loads is very important to ensure the safety of the design (Heisel *et al.*, 2020). Research has been conducted to investigate the aerodynamics of the higway signs, such as Letchford (2001), Quinn *et al.* (2001), Wang *et al.* (2016) and DeMello *et al.* (2019). Moreover, some design standards such as ASCE/SEI (7-16) and AASHTO (2016) have provided guidelines for the calculations of the wind loads acting on these structures. In comparison, these guidelines are missing from the Australian standards AS/NZS 1170.0:2011 (2016). Besides, limited research has been conducted on the effect of the interaction between the highway sign with its supporting structure. In this study, the effect of the sign geometry such as sign size (area) and sign aspect ratio on the aerodynamic force coefficients of a pole type supporting structure investigated experimentally. The selection of the sign geometry has been guided by AS 1743:2018 (2018) and AS 1742.15 (2019). The effect of the pole cross-section shape on the aerodynamic force coefficients has been studied as well.

2. Wind Tunnel Experiments

The experimental work was performed in the Boundary Layer Wind Tunnel (BLWT) at the University of Sydney. The BLWT is capable of reaching a maximum wind velocity of 27 m/s across its 2500 mm x 2000 mm cross-section. The experiments have investigated the effect of the highway sign geometry on its supporting structure. In this study, a pole type supporting structure has been adopted with a prototype diameter (d_{pole}) of 225 mm and height (L_{pole}) of 6000 mm. A pole model with a diameter equal to 45 mm and height equal to 1200 mm is used to simulate the prototype at a scale-down factor of (1:5). Two models with square and dodecagon (12-sided section) cross-sections have been used. To maintain consistency, signs are scaled using the same factor. Five sign sizes are investigated with three sign length (L_{sign}) to sign width (W_{sign}) ratios (1:1, 1:2 and 1:4). The signs are mounted on the model pole using a U-bolt. The centre of the sign width is aligned with the centre of the pole diameter. While the centre of the sign length was aligned with the top of the pole height, as shown in Figure 2(a). The model is mounted on a High-Frequency Base Balance (HFBB) which was fixed on the wind tunnel turning table, as shown in Figure 2(a). The wind velocity is set to 10 m/s in this study with a constant incoming velocity profile on the sign and low turbulence intensity (below 0.5%). The data is collected for a period of 300 sec with a sampling frequency of 1024 Hz. Moreover, the effect of wind flow angle (θ) is studied by changing the angle of attack from 0 to 90 degree) with an increment of 15 degrees, as shown in Figure 2(b).



(a) (b)

Figure 2. Experimental settings (a) Schematic front and side view (b) Plan view

3. Investigated Cases and Results

With reference to the parameters mentioned in the previous section, 10 cases are conducted in this study. For each case, seven wind flow angles are applied. In addition, experiments are conducted to study the effect of the pole cross-sectional shape on the aerodynamic coefficients and compared to those of a circular pole (C). The investigated cases are summarized in Table 1.

Table 1. Investigated cases

Pole cross-section	L_{sign} (mm)	W_{sign} (mm)	Sign aspect ratio	Wind flow angle (degree)
Square (SQ)	-	-	-	0 – 90
	135	135	1:1	0 – 90
	135	270	1:2	0 – 90
	180	360	1:2	0 – 90
	180	720	1:4	0 – 45
	360	360	1:1	0 – 90
Dodecagon (DO)	-	-	-	0 – 90
	135	135	1:1	0 – 90
	135	270	1:2	0 – 90
	180	360	1:2	0 – 90
	180	720	1:4	0 – 45
	360	360	1:1	0 – 90
Circle (C)	-	-	-	0 – 90

Based on the adopted orientation, shown in Figure 2(b), the aerodynamic force coefficients along the x-axis (C_{F_x}) and along the y-axis (C_{F_y}) have been calculated using Equation 1.

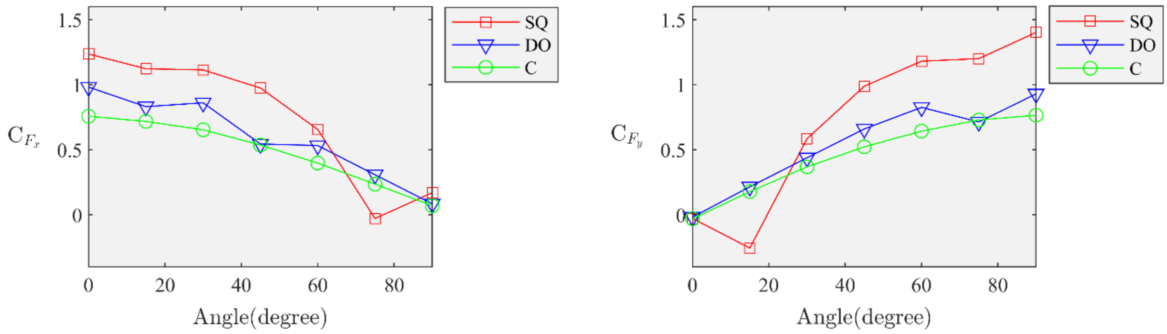
$$C_{F_x} \text{or } C_{F_y} = \frac{2\,(F_x \text{ or } F_y)}{\rho_{air}\, V^2 (A_x \text{ or } A_y)} \quad (1)$$

Where: (F_x or F_y): the mean force in (N) along the x-axis and the y-axis, respectively. (ρ_{air}): the density of air (= 1.225 kg/m^3). (V): the wind velocity (= 10 m/s). (A_x or A_y): is the projected area in the x-axis and the y-axis respectively in (m^2). In the cases where the sign was attached to the pole, the obtained results from Equation (1) will represent the equivalent aerodynamic force coefficients ($C_{F_{x\,eq}}$ and $C_{F_{y\,eq}}$) for the entire structure along the x-axis and the y-axis respectively, and the area used is the total sum of the sign area in the direction of interest and the exposed area of the pole in the same direction.

3.1 Effect of pole cross-sectional shape

To investigate the effect of the pole cross-sectional shape on the aerodynamics, two experiments are conducted for the pole models without signs. They are compared to the results of a circular pole. The results of the aerodynamic force coefficients are shown in Figure 3.

The results, shown in Figure 3, have clearly stated that the aerodynamic force coefficients for the square shape are higher than those for the dodecagon shape by 30 % and those for the circular shape by 60 %. Moreover, negative values occur for the aerodynamic force coefficients for the square cross-sectional shape at 15-degree angle between the wind flow direction and the nearest main axis of the pole. These negative values are due to the separation, and the reattachment of the wind flow around the sharp corner ESDU-71016 (1978).

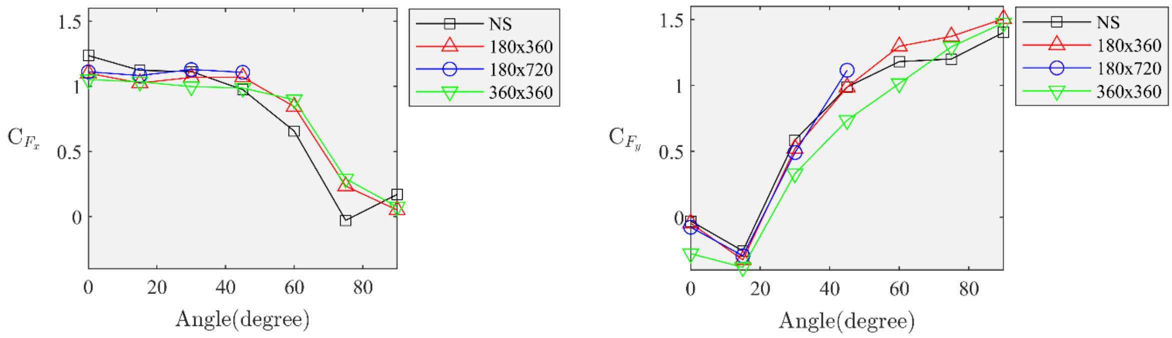


(a) (b)

Figure 3. Effect of pole cross-sectional shape on aerodynamic force coefficients (a) along the x-axis (b) along the y-axis

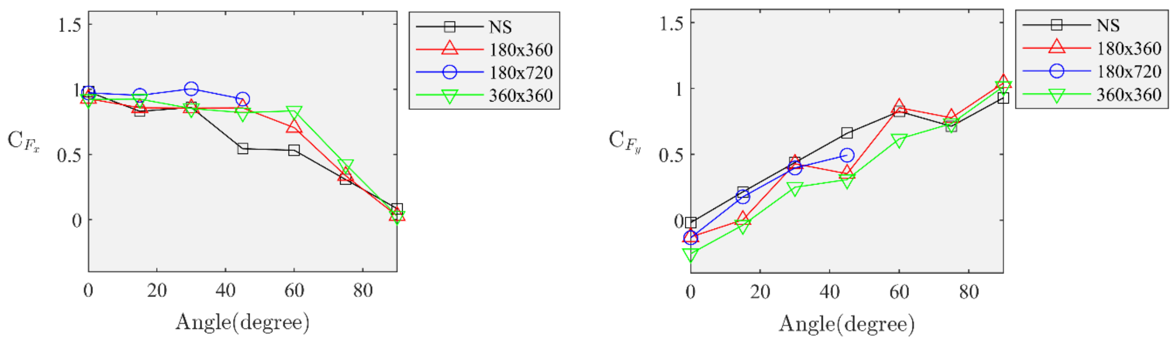
3.2 Effect of sign aspect ratio

The effect of the sign aspect ratio is studied by adopting three different aspect ratios. The results of the pole with a square section are presented in Figure 4. Also, the results of the pole with the dodecagon section are summarized in Figure 5. Based on the results shown in Figure 4, the presence of a sign attached to the pole reduces/eliminates the negative value of the aerodynamic force coefficient along the x-axis. In comparison, no effect is noticed for the aerodynamic force coefficient along the y-axis. Also, the change in the aerodynamic force coefficients in both the x-axis and the y-axis is observed to be within 5 % as the aspect ratio changed from (1:1) to (1:4). As a result, the effect of the sign aspect ratio is found to be limited in this study for both cross-sectional shapes.



(a) (b)

Figure 4. Effect of sign aspect ratio on the aerodynamic force coefficients of a square shape pole (a) along the x-axis (b) along the y-axis

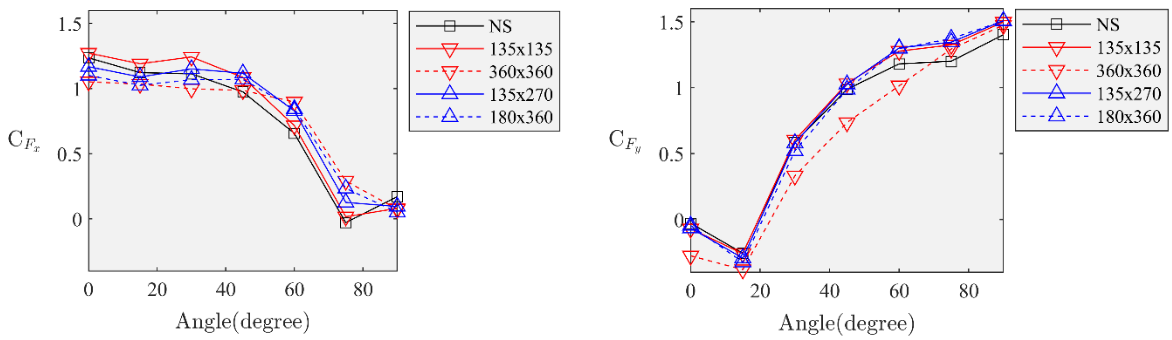


(a) (b)

Figure 5. Effect of sign aspect ratio on the aerodynamic force coefficients of a dodecagon shape pole (a) along the x-axis (b) along the y-axis

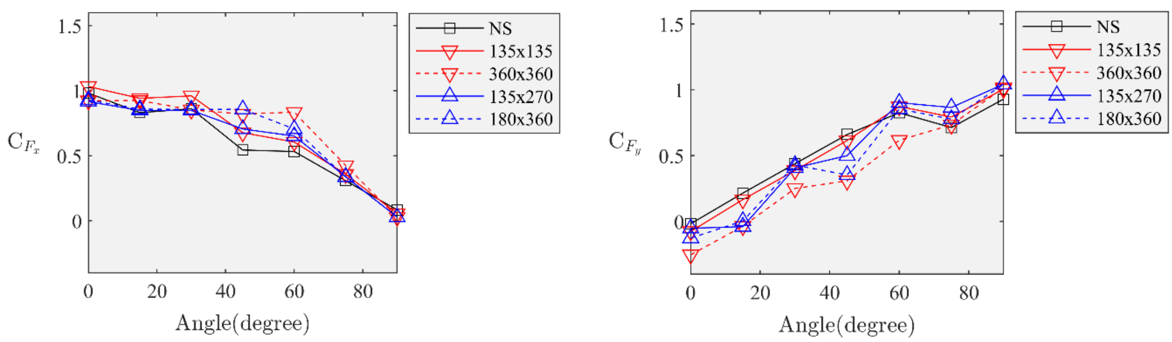
3.3 Effect of sign area

The effect of the sign area is investigated by conducting experiments with signs that have the same aspect ratio but different total area. The adopted sign aspect ratios for this purpose are (1:1 and 1:2). The results of the pole with a square section are presented in Figure 6. Also, the results of the pole with the dodecagon section are summarized in Figure 7.



(a) (b)

Figure 6. Effect of sign area on the aerodynamic force coefficient for square section (a) along the x-axis (b) along the y-axis



(a) (b)

Figure 7. Effect of sign area on the aerodynamic force coefficients for dodecagon section (a) along the x-axis (b) along the y-axis

The results presented in the figures above show that as the area of the sign increases through the flow angle range from 0 - 45 degrees, the aerodynamic force coefficients decrease. However, the aerodynamic force coefficients are found to increase with an increase of sign area when the flow angle ranges from 45 - 75 degrees. This occurs due to the increase of the total projected area within this range.

4. Conclusions

Based on the results presented in the previous section, the following conclusions can be made:

- Negative values for the aerodynamic force coefficients are generated due to the separation and reattachment of the wind flow around the sharp corner of the pole with a square cross-section at an angle of 15-degrees.
- When no sign is attached, the use of a pole with a dodecagon cross-section or circular cross-section can reduce the aerodynamic forces by a range of 30 - 60 % when compared to a pole with a square cross-section.
- The presence of a sign attached to the pole with a square cross-section reduces/eliminates the negative values for the aerodynamic force coefficient in the x-axis. While, along the y-axis, the negative values remain almost the same.

- The effect of the sign aspect ratio on the aerodynamic force coefficients is limited regardless of the pole's cross-sectional shape.
- For the same sign aspect ratio, as the area of the sign increases, the aerodynamic force coefficients decrease for a flow angle ranged from 0 - 45 degrees. However, the aerodynamic force coefficients increase as the flow angle ranged from 45 - 75 degrees. This occurs due to the increase of the total projected area within this range.

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