Journal of Wind Engineering & Industrial Aerodynamics 179 (2018) 70–79

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia

Wind load effect of single-column-supported two-plate billboard structures

Zhihao Li [a], Dahai Wang [a,*], Xinzhong Chen [b], Shuguo Liang [c], Jie Li [d]

[a] School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan, Hubei, China
[b] National Wind Institute, Department of Civil, Environmental and Construction Engineering, Texas Tech University, Lubbock, TX, USA
[c] School of Civil Engineering, Wuhan University, Wuhan, Hubei, China
[d] State Key Laboratory of Disaster Reduction in Civil Engineering, School of Civil Engineering, Tongji University, Shanghai, China

ARTICLE INFO

Keywords:
Billboards
Wind pressures
Aeroelastic model test
Aerodynamic admittance function
Aerodynamic damping
Alongwind response
Torsional response

ABSTRACT

Wind tunnel studies are conducted to investigate the wind load effect of a representative single-column-supported two-plate billboard structure. Firstly, synchronous pressure measurement on the billboard of a rigid model in wind tunnel is carried out. The alongwind, acrosswind and torsional loads at different wind directions are analyzed. Simplified pressure distributions causing alongwind and torsional loads at the most unfavorable wind directions are presented. Secondly, an aeroelastic model test is conducted and the response at the base of supporting column is obtained from force balance measurement. The measured responses are also compared with the analytical predictions to validate the effectiveness of analytical approach. This analysis sheds new insight on the aerodynamic admittance function and aerodynamic damping. A simplified approach for the analysis of torsional response is introduced in terms of effective eccentricity coefficient. This study provides comprehensive wind load testing data and analytical approach for prediction of wind-induced response of two-plate billboard structures.

1. Introduction

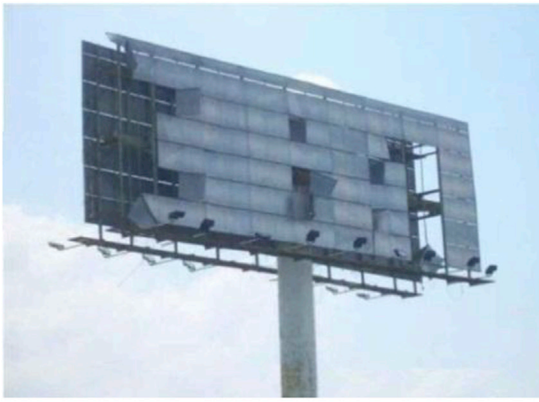
The large single-column-supported billboard structures are widely used for outdoor advertisement. This type of structures are primarily composed of upper (two or three) rectangular billboards which are supported by enclosed trusses or frames, and a vertical steel pole support. The back-to-back thin plates with open sides, referred to as two-plate billboards, are arranged with small inclined angle or parallel to each other. Their overall heights are up to 20–50 m above the ground. The rectangular boards are usually 20–30 m in length and 5–10 m in height. This type of cantilever structures have relatively large windward area, which is subjected to large wind load. Damages and failures of the large billboard structures due to hurricanes or other types of strong winds have been frequently reported (e.g., An, 2009; Tamura and Cao, 2009). These can be categorized as three type of destructions, i.e., damage of plate cladding, failure of supporting structure, and overthrow of overall structure result from failure of foundation (Song and Ou, 2009; Wang et al., 2010), as shown in Fig. 1.

Extensive studies have been performed to investigate wind loading on low-rise single rectangular plates and free-standing walls. Letchford and Holmes (1994, 2001) conducted wind tunnel tests to investigate pressure and drag force coefficients of infinite and semi-infinite free standing walls, as well as finite walls with different aspect ratio. The drag force coefficients of a range of single rectangular plate with varying aspect ratio and clearance ratio were also measured through force transducers. These results helped in developing wind load standards to guide the design of sign structures (e.g.,ASCE, 2010; AS, 2011). Warnitchai et al. (2009) conducted wind tunnel test of single-plate, two-plate and V-shaped billboards to study the variation of drag force coefficient and eccentricity with wind directions. Zuo et al. (2014) performed comprehensive wind tunnel experiments based on both pressure and force measurements to investigate wind force coefficients of box-shape and parallel two-plate as well as V-shaped signs. Smith et al. (2014) carried out a full-scale pressure measurement of box-shape LCD sign that is commonly used in the United States, and verified the accuracy of wind tunnel test. Han and Gu (2015) studied the pressure distribution characteristics on inside and outside of two-plate billboards, and calculated wind-induced response without consideration of aerodynamic damping effect. Wang et al. (2016) investigated the distribution characteristics of net wind pressure of two typical billboards. In addition, Meyer et al. (2015) conducted an aeroelastic model test of variable message sign crossing highway, investigated wind-induced vibrations due to vortex shedding and galloping.

This study presents wind tunnel investigations and analysis of the

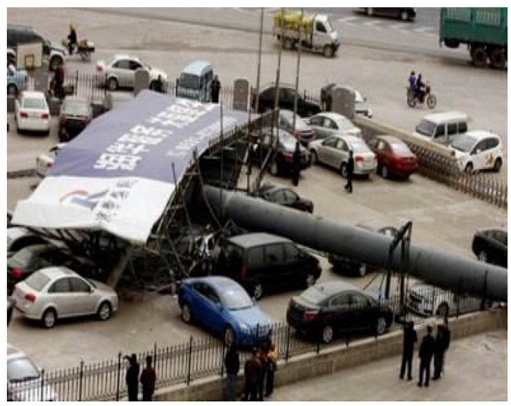
* Corresponding author.
E-mail address: wangdahai@whut.edu.cn (D. Wang).

https://doi.org/10.1016/j.jweia.2018.05.013
Received 27 January 2018; Received in revised form 5 May 2018; Accepted 21 May 2018



(a) Damage of plate cladding

(b) Failure of plate supporting structure



(c) Failure of foundation

Fig. 1. Three typical failure modes of large billboards.

wind load effect on a representative single-column-supported two-plate billboard structure. Firstly, the alongwind, acrosswind and torsional loads at different wind directions are analyzed based on synchronous pressure measurement in wind tunnel. Secondly, the response at the base of supporting column is measured using force balance from an aeroelastic model test. The characteristics of response are analyzed, and are compared with the analytical predictions. The importance of consideration of aerodynamic admittance function and aerodynamic damping effect is emphasized. A simplified approach is also introduced for the estimation of torsional response in terms of effective eccentricity.

2. Wind pressures and loads on billboards

2.1. Pressure measurements

In light of Chinese design practice (07SG526, 2007), a commonly used G2-5 × 14 of two-plate billboard structure was selected as a representative structure for this study. The prototype structure is 18 m in height. The elevation and plan view of the scaled rigid model are shown in Fig. 2. The length scale ratio of the model is 1/20. The structural dimensions and the angel between the two plates are listed in Table 1.

The plates of rigid model was made of light pine wood. The supported column was made of aluminum alloy in circular cross section with 40 mm in diameter. The model was fixed on the wind tunnel floor with nuts. The layout of pressure taps on boards is shown in Fig. 3(a). Pressure taps at the same corresponding positions of two facades were placed to get net pressure measurements. Each face consisted of 90 pressure taps thus a total of 90 × 4 = 360 pressure taps were used. The wind tunnel test was conducted in Boundary Layer Wind Tunnel at the State Laboratory for Disaster Reduction of Civil Engineering in Tongji University, China. The sampling frequency of the wind pressure measurement was 300 Hz with a time duration of 135 s, which corresponds the prototype time of 10 min when the wind speed ratio is 1/4.47. The testing model in wind tunnel is shown in Fig. 3(c).

The profiles of mean wind speed and longitudinal turbulence intensity, and the power spectral density (PSD) of longitudinal turbulence are shown in Fig. 4. The mean wind speed, and turbulence intensity at the reference height $z_h = 89$ cm were 9.77 m/s and 7.6%, respectively. The integral length scale of longitudinal turbulence in alongwind and crosswind

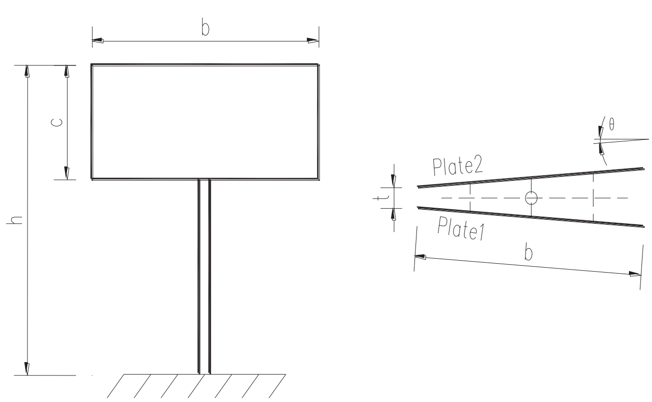


Fig. 2. Elevation and plan view of a two-plate billboard structure model.