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Experimental study of wind loading of rectangular sign structures

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ABSTRACT

A three-phase experimental campaign was conducted to study wind loading of sign structures with rectangular sign faces. Full-scale measurements and wind-tunnel tests conducted in phase 1 of the studies showed consistent results for wind loading of a prototype rectangular box sign and its scaled model, validating the methodologies used in the wind tunnel tests. Five models of representative rectangular signs of different configurations were tested in the wind tunnel as the second phase of the study, the results of which revealed the significant influence of the geometrical configuration of rectangular sign structures on their wind loading. Motivated by the observations made in this phase of comparative investigation, an extensive series of wind tunnel tests were performed in the last phase of the study to evaluate wind loading of rectangular box signs of various configurations. The effects of the aspect and clearance ratios on wind loading of rectangular box signs are highlighted based on this phase of the study.

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1. Introduction

Rectangular boxes and plates are frequently used as signs to display information and to also function as a structural component. These sign systems with rectangular faces are structurally quite simple: they usually consist of primarily up to two rectangular sign boards or an enclosed rectangular box and a simple support in the form of a mono-pole or a truss. In some other cases, the rectangular signs are simply fixed to the ground. Despite the structural simplicity of these structures and the fact that rectangular boxes and plates are among bluff bodies of the simplest in shape, the wind loading of sign structures can be complex and is dependent on the size of the sign, the ratios between the three dimensions (i.e., width, height and depth) of the sign, whether the sign is elevated or located on the ground and, in the case of an elevated sign, the amount of clearance between the sign and the ground.

To date, although extensive research have been performed to investigate wind loading of bluff bodies that resemble signs of rectangular plate or box in shape, few studies have been conducted to expressly investigate the wind loading of rectangular sign structures. Flachsbart conducted one of the earliest wind-tunnel experiments to measure the wind pressure acting on a rectangular plate of various aspect (i.e., width to height) ratios in uniform smooth flow. His study highlighted the difference in the loading of the rectangular plates when they are on and elevated from the ground plane. The results of this investigation, which are summarized by Simiu and Scanlan (1996) formed a benchmark for subsequent studies motivated by the application in the design of flat plates. In particular, a number of studies used wind-tunnel experiments to highlight the wind loading of two dimensional plates in turbulent uniform flow (e.g., (Bearman, 1971)) and turbulent boundary layer flow (e.g., (Good and Joubert, 1968; Sakamoto and Arie, 1983)) as opposed to smooth uniform flow as in the case of the study by Flachsbart.

These early wind tunnel studies were followed by a number of wind-tunnel, full-scale and numerical studies that were conducted to assess wind loading of free-standing walls, which resemble signs composed of a single rectangular plate fixed to the ground. For example, Letchford and Holmes (1994) performed independent wind-tunnel tests to study wind loading of models of infinite (i.e., spanning the entire width of a wind tunnel) and semi-infinite (i.e., spanning half the width of a wind tunnel) walls as well as finite walls of various aspect ratios in appropriately simulated boundary layer flow. In these tests, transducers were used to measure wind pressure acting at discrete locations on portions of the wall models, based on which the pressure coefficients at the instrumented locations of the models as well as the force

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coefficients of the whole models were estimated. The results of these wind-tunnel studies were subsequently codified and introduced into design standards despite some inconsistencies in the data sets obtained in the wind tunnel tests (Robertson et al., 1996). To address the inconsistencies, full-scale measurements using pressure transducers were conducted to study wind loads on free-standing walls (Robertson et al., 1995–1998) of various aspect ratios. In addition, both numerical studies based on computational fluid dynamics (Robertson et al., 1997) and additional wind tunnel experiments (Letchford and Robertson, 1999) were also conducted. In particular, the numerical study suggested that it is challenging for the model to adequately simulate the complex three-dimensional flow created by the wall of simple rectangular shape.

Although these previous studies on wind loading of free-standing walls were quite comprehensive and thorough, the outcomes of the studies apparently are only applicable to sign structures composed of a single thin plate fixed to the ground. As indicated in (Robertson et al., 1997), the pressure and force coefficients of these thin walls can be much higher than those of the ground level signs composed of thick rectangular boxes. Also, the wind loading of elevated rectangular sign structures had not been systematically studied. Subsequently, Letchford (2001) conducted wind tunnel experiments to specifically investigate wind loading of structures consisting of a single thin rectangular plate, which can be either on the ground or elevated. He used force transducers to directly measure the forces and moments acting on rectangular plates of various aspect ratios and, on this basis, estimated the mean and pseudo-steady force coefficients of these models for a number of wind directions. In addition, the study also evaluated wind-induced torque about the vertical axis of the sign models. The extensive data set obtained in this investigation were subsequently combined with those from previous studies on wind loading of free-standing walls and codified to form standards (e.g., (ASCE, 2010)) to guide the design of sign structures.

These early data sets, as well as a more recent studies that investigated the effect of the porosity of the rectangular panels (Briassoulis et al., 2010; Giannoulis et al., 2012) on their wind loading, however, were all derived from studies of wind loading of a single thin plate and may not be applicable to rectangular signs of other types of configuration. Indeed, a recent study based on wind tunnels tests (Warnitchai et al., 2009) has shown that the force and moment coefficients of a sign structure consisting of two rectangular sign plates in either parallel or oblique configurations can be significantly different from those of a sign composed of a thin rectangular plate of the same aspect (i.e., the width to height of the sign face) and clearance (i.e., the height of sign face to the total height of the structure) ratios. Also, although many studies have been conducted to study wind loading of rectangular cubes, such studies were either conducted in uniform smooth or turbulent flow (e.g., (Laneville et al., 1975)) or in turbulent boundary layer flow but for shapes on the ground plane representing a rectangular building but not a typical rectangular sign box.

This paper presents the results of a three-phase experimental campaign that incorporated both full-scale and model-scale studies to investigate the wind loading of rectangular sign structures. In the first phase of the campaign, the wind loading on a full-scale rectangular sign structure was monitored in the field and a scaled model of this structure was tested in the wind tunnel using both pressure and force measurement techniques. In the second phase, five models of representative rectangular signs of different configurations were tested in the wind tunnel using the force measurement technique validated in the first phase of the study to reveal the significant influence of the geometrical configuration of rectangular sign structures on their wind loading. In the third phase, an extensive series of wind tunnel tests were performed to evaluate wind loading of rectangular box signs of various configurations.

The focus of the paper is on the outcomes of the wind tunnel tests of scaled sign models, while the results from the full-scale study are used only for validation of the methodologies used in the wind tunnel tests. The data collected from the study are processed and presented in the forms of force coefficients and eccentricity coefficients, the latter of which are measures of the wind-induced torque acting on the sign or sign models subjected to testing. Based on an interpretation of these coefficients, the effects of the geometric configuration of rectangular sign structures on their wind loading are highlighted, and the dependence of the wind loading of rectangular box signs on the aspect and clearance ratios are evaluated.

2. The full-scale structure and the measurement system

As part of a research effort to understand the wind loading of rectangular signs, a full-scale sign structure was installed at the field test site at Texas Tech University for long term monitoring. Fig. 1 shows this structure and its immediate surrounding terrain, which is flat and homogeneous with few obstructions. Fig. 2 shows the histogram of the roughness length (z_0) of the terrain shown in Fig. 1, which is estimated based on 10-min mean wind speed values measured by two ultrasonic anemometers located at 0.91 m and 2.44 m, correspondingly, above ground level on an adjacent 200 m meteorological tower with the assumption that the mean wind speed profile is logarithmic in nature and that the effect of the atmospheric stability can be neglected, that is,

$$U(z) = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right) \tag{1}$$

Fig. 1. A prototype rectangular sign structure subjected to monitoring.

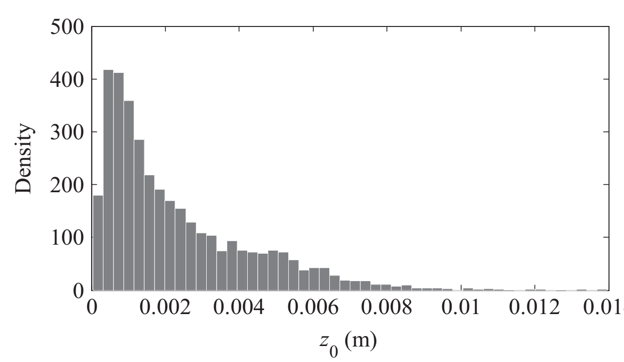

Fig. 2. Histogram of estimated roughness length of the field test site.