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Wind tunnel study of wind-induced torques on L-shaped tall buildings

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ABSTRACT

L-shaped tall buildings are commonly built in urban areas due to shortage of land and graceful demand of architectural design. In this study, eight L-shaped rigid models with different geometric dimensions are tested in a boundary wind tunnel to study the characteristics of the wind-induced torques acting on L-shaped tall buildings. RMS force coefficients, power spectral densities and vertical correlation functions of the wind-induced torques are analyzed and discussed in details. Based on the wind tunnel test results, empirical formulas which take the buildings' side ratio and terrain category as key variables are proposed for estimating the wind-induced torques on L-shaped tall buildings. A simplified expression to evaluate the wind-induced torques on L-shaped tall buildings is derived based on the proposed formulas and its applicability has been verified by a case study. This study aims to provide a simple and effective way for the estimation of wind induced torque on L-shaped tall buildings.

1. Introduction

A large number of irregular shaped tall buildings have been built in recent years due to shortage of land in urban areas and graceful demand of architectural design. The irregular shapes of these buildings may make them more sensitive to wind excitations than regular shaped tall buildings, especially in across-wind direction and torsional moments. It has been widely recognized that external shapes of tall buildings play an important role in the generation of wind loads on high-rise structures. However, current design codes and standards (AIJ, 2004; ASCE, 2010; GB50009, 2012) generally only provide guidelines for estimating the wind effects on tall buildings with regular and symmetric shapes. Actually, there is no analytical formula available for evaluation of the wind effects on irregular shaped tall buildings. Therefore, it is necessary to conduct extensive research works on this topic.

Stathopoulos and Zhou (1993) adopted numerical simulation methods to predict the wind pressures on surfaces of various buildings with sharp corners. Gomes et al. (2005) investigated the wind effects on L and U-shaped building models by use of both wind tunnel testing and numerical simulation approach. Gu (2009) carried out wind tunnel tests on 27 typical tall building models and analyzed the characteristics of wind-induced pressures and forces on these buildings. Cluni et al. (2011) compared the wind loads on regular and irregular tall buildings by high order moment statistical analysis. Kim and Kanda (2013) investigated the spatial-temporal characteristics of pressure fluctuations on tapered and set-back tall buildings. Chakraborty et al. (2014) investigated the wind pressure distributions on a '+' shaped tall building by wind tunnel testing and numerical simulation. Cheng et al. (2015) studied the characteristics of fluctuating wind pressures on side faces of H-shaped tall buildings and the shape effect on the generation of across-wind forces with the space-time statistical tool of proper orthogonal decomposition.

The previous studies on the wind effects on irregular shaped tall buildings mostly focused on the pressure distributions on tall building models but rarely referred to the overall wind loads especially torsional loads. It has been reported that wind induced displacements and accelerations at corners of tall buildings can be amplified by the wind-induced torsional vibration and cause uncomfortable feeling of the residents (Tallin and Ellingwood, 1984, 1985). Liang et al. (2004) studied the torsional wind loads on rectangular tall buildings and established empirical formulas of base torque spectra. Li et al. (2014) investigated the characteristics of wind-induced torques on rectangular tall buildings and presented a simplified expression to evaluate the dynamic torsional wind loads. It is well known that the mechanisms of generation of wind-induced torques, such as the wake excitation, are strongly correlated with external shapes of tall buildings. However, the provisions stipulated in design codes and standards are established

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Fig. 1. Examples of L-shaped tall buildings.

mainly from experimental results of regular building models like square or rectangular sectional models. Hence, estimation of wind-induced torques on irregular shaped tall buildings based on current provisions may not be reasonable. In recent years, a large number of L-shaped tall buildings have been built throughout the world. Fig. 1 shows examples of L-shaped buildings. The overall wind loads acting on L-shaped tall buildings including along-wind and across-wind forces as well as and torques have rarely been reported. Based on extensive wind tunnel tests, the along-wind and across-wind loads on L-shaped tall buildings have been studied in detail and related spectra and parameters for evaluating these wind loads have been proposed (Li, 2014; Li and Li, 2016). However, there is lack of guideline for estimation of the wind-induced torques on complex structures with torsional irregularity such as L-shaped tall buildings.

In this paper, eight L-shaped tall building models with different geometric dimensions are tested by simultaneous pressure measurement technique in a boundary wind tunnel to study the characteristics of wind-induced torques acting on L-shaped tall buildings. Based on the experimental results, RMS force coefficients, power spectral densities and vertical correlation functions of the wind-induced torques are presented and discussed, and empirical formulas are proposed by use of the none linear least-squares method (NLSM). In the light of structural dynamics method and random vibration theory, a simplified expression to evaluate the wind-induced torques on L-shaped tall buildings is derived based on the proposed formulas. The applicability of the proposed simplified formula is verified through a case study.

2. Wind tunnel test

Due to complex mechanisms of generation of torques on bluff bodies, it is difficult to deduce analytical formulas for estimation of wind induced torque on tall buildings. It has been widely accepted that wind tunnel test is the most effective tool to study the characteristics of wind-induced torques on tall buildings.

2.1. Features of approaching wind flows

Wind tunnel test was conducted in a boundary layer wind tunnel laboratory at Hunan University, China. In order to evaluate the effects of terrain category, four different kinds of terrain categories specified in the Loads Standard Code of China (GB50009-2012) were simulated by different combinations of spires and roughness elements in the wind tunnel test. Due to limited space of this paper, only the profiles of mean wind speed and turbulence intensity of terrain category C at a length scale 1:500 are illustrated in Fig. 2, while the profiles and related information of the other wind fields simulated in the wind tunnel test

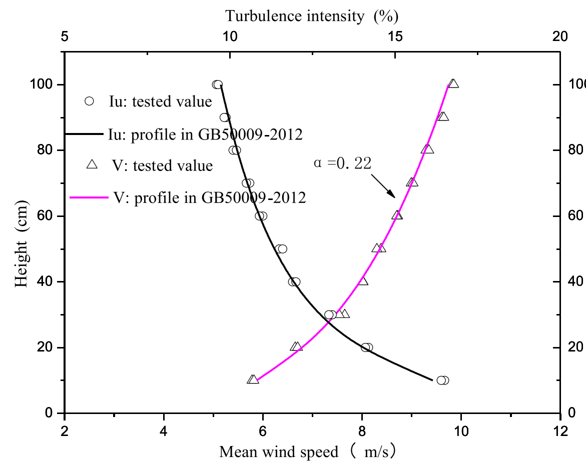

Fig. 2. Mean wind speed and turbulence intensity profiles in category C.

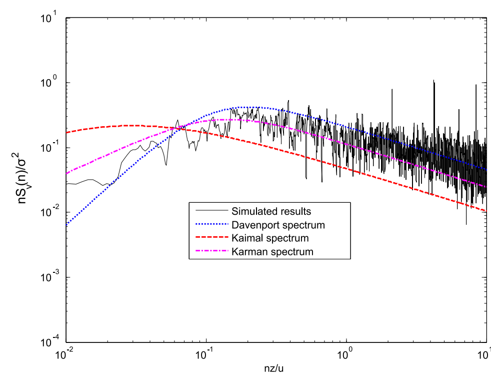

Fig. 3. Longitudinal velocity spectra at reference height of 0.6 m.

were described in Li (2014). The corresponding longitudinal velocity spectra of the simulated boundary layer flows at the reference height of 0.6 m above the floor of the wind tunnel test section are plotted in Fig. 3, which are in good agreement with the von Karman spectrum. In addition, the experiments were also conducted in uniform smooth flow for comparison purposes.

2.2. Test arrangements

Eight rigid models with different configurations of L-shape (called M1, M2, M3, M4, M5, M6, M7, M8) were built for the wind tunnel test and their geometric parameters are shown in Table 1. It can be seen that M1, M2, M3, M5, M7, M8 are L-shaped models with different side ratios D/B, while M4, M5, M6 are those with different aspect ratios H/B. All the test models were made of ABS (Acrylonitrile Butadiene Styrene) material to ensure sufficient strength and rigidity of the models. Pressure taps on the models were connected to electronic pressure scanning modules by plastic tubes. Numerical compensation was employed to correct the tubing effects prior to data processing (Li, 2014). The maximum blockage ratio in the wind tunnel experiment was about 1.3% for all the models tested in this study.

Fig. 4 shows the definition of wind direction and locations of pressure taps on the experimental models. The mean wind speed at the gradient height was kept as 12 m/s for the wind tunnel test of all the models. Electronic pressure scanning modules made by Scanivalve Inc. (USA) were used to measure instantaneous wind-induced pressures on the surfaces of the models. Pressure measurements on the L-shaped models were conducted for wind direction from 0° to 360° at 10° intervals with additional directions 45°, 135°, 225°, 315° so that the total number of wind direction considered in the model test was 40. The data sampling frequency was set to be 312.5 Hz and the sampling