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Monitoring of wind effects on 600 m high Ping-An Finance Center during Typhoon Haima

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ABSTRACT

This paper presents analyzed results of field measurements of wind-induced pressures on building claddings and structural responses of 600 m high Ping-An Finance Center (PAFC) in Shenzhen, China during the passage of Typhoon Haima. The characteristics of cladding pressures during the typhoon were investigated with highlights on energy distribution, non-Gaussian probability and coherence features. Then, the natural frequencies, damping ratios and mode shapes of the skyscraper were presented. Based on the field measurements, the amplitude-dependent characteristics of the modal parameters were discussed and the range of selection of damping ratio for the wind-resistant design of super-tall buildings was recommended. Finally, the serviceability of the skyscraper under typhoon condition was assessed. This paper aims to further understand the wind effects on super-tall buildings and provide useful information for the design of skyscrapers in tropic cyclone prone regions.

1. Introduction

In recent years, numerous skyscrapers, such as 828 m high Burj Khalifa, 632 m high Shanghai Tower and 600 m high Ping-An Finance Center (PAFC), have been built. These modern skyscrapers with increasing building height, relatively low natural frequency and damping ratio become more sensitive to wind excitations than those in the past. Hence, wind effects on these skyscrapers have become a major concern in their wind-resistant structural design. Though the assessment of wind-effects on high-rise structures can be performed via wind tunnel tests or numerical simulations by Computational Fluid Dynamics (CFD) techniques, there are some issues or limitations to be improved or overcome, such as the properly modelling of approaching wind fields for wind tunnel tests and the validity and accuracy of CFD simulation results need to be verified or improved [4,30]. Field measurement has been regarded as the most reliable means to evaluate the wind effects on high-rise buildings.

Field investigations of structural dynamic properties and wind-induced responses have been performed on a number of high-rise buildings over the last decade, such as three skyscrapers in Chicago [12,13], more than ten tall structures in Hong Kong, mainland China and Taiwan, including Central Plaza Tower and Di Wang Tower [17], CITIC Plaza Tower and Jin-Mao Building [18], Guangzhou West Tower [6] , Taipei 101 Tower [19], Canton Tower [5,9]. These studies have enhanced the understanding of structural modal parameters and wind-induced vibrations of high-rise structures. However, with the growing trend of continuously increasing number of skyscrapers with higher altitudes and varied appearances and complex configurations in recent years, the performance of skyscrapers during windstorms such as tropical cyclones are still needed to be further investigated by field measurement or monitoring.

This paper presents a field investigation of the wind effects on 600 m high PAFC located in Shenzhen, China, during Typhoon Haima. Detailed analysis of the field measurements during the passage of the typhoon, including wind speed and direction, wind-induced pressures on cladding and structural acceleration responses, is carried out to investigate the structural dynamic properties and wind-induced responses of the skyscraper under typhoon condition. The objective of this study is to further understand the wind effects on super-tall buildings and provide useful information for the wind-resistant design of future skyscrapers. The paper is organized as follows: Section 2 introduces structural system of PAFC, field measurement arrangement and Typhoon Haima. Section 3 presents the observations of wind speed and direction during the passage of the typhoon. The following section focuses on the analysis of the wind-induced pressures on building claddings. Section 5 discusses structural acceleration responses, structural

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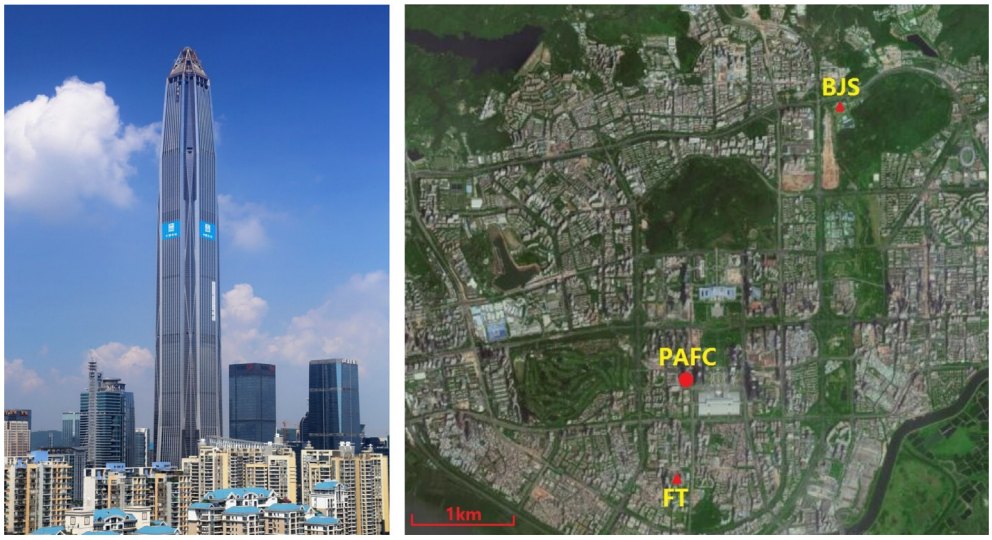

(a) Building exterior (b) Building location

Fig. 1. Building exterior and location of PAFC.

modal parameters and presents a serviceability assessment of the skyscraper. Finally, the main findings and conclusions of this field monitoring study are summarized in Section 6.

2. Introduction of PAFC and Typhoon Haima

2.1. PAFC

PAFC shown in Fig. 1 is located at the central business district of Futian in Shenzhen where is a coastal city in the south of China. With its main structure erecting to 600 m high from the ground, PAFC is currently the fourth highest building in the world and the second tallest structure in China. The skyscraper consists of 118 floors above the ground and has a footprint of 63 × 63 m. To enhance the resistance to lateral and vertical loads for such a high and slender building, PAFC comprises a mega-frame core tube structure including: eight steel-reinforced concrete mega-columns, reinforced concrete core tube, and four outrigger trusses that connect the core tube with the mega-frame.

2.2. Measurement arrangement

In this study, measurement devices at four selected floors in PAFC were deployed during Typhoon Haima to record wind-induced pressures on building claddings, and structural acceleration responses. The layout of the measurement devices is depicted in Fig. 2.

a. *Anemometers*

Wind speed and direction records monitored by two cup-type anemometers at two automatic weather stations in Shenzhen shown in Fig. 1(b) during the passage of Typhoon Haima were used in this paper to demonstrate the typhoon-generated wind characteristics. One weather station is located at Futian (FT) nearby PAFC (about 1.3 km away along the south direction) with altitude of 120 m atop an office building. The other is located at Bijiashan (BJS) about 4.3 km away from PAFC along the northeast direction with altitude of 31 m atop a factory building. The two stations provide 5-min mean wind speed and direction records.

b. *Pressure transducers*

As indicated in Fig. 2, pressure transducers were installed on the building claddings at the 81st floor of PAFC. To obtain the pressure measurements at representative locations on the building surfaces, the centers of the four building sides and four corners at the 81st floor were equipped with Setra268 pressure transducers (Setra systems, Inc. Boxborough, Massachusetts), as shown in Fig. 2(b). The full-scale range (FS) and accuracy of the transducers are 2.5 kPa and 0.25% FS (or, 6.25 Pa), respectively. The dynamic pressure of the exterior wind was imported into the transducer through a plastic tube while the reference static pressure was derived from a box installed inside the building. During the pressure measurements, analog signals collected by the transducers were then acquired and digitized at a sampling frequency of 20 Hz by a set of high-resolution digital data logger (National Instruments Corporation, Austin, Texas), including cDAQ-9174 (USB chassis) and 9234 (signal acquisition module).

c. *Accelerometers*

As shown in Fig. 2, accelerometers were installed along two orthogonal directions (east–west and north–south) at four floors: 49th, 81st, 100th and 118th. The two directions are denoted to be “A-1” (east–west) and “A-2” (north–south) in the following analysis. To ensure the acceleration measurements with desirable accuracy, each of the four floors was equipped with two pairs of low-frequency oriented accelerometers with different detection ranges and accuracy at nearby locations. Moreover, in order to detect the information of torsional modes as much as possible, the accelerometers were placed specifically at corners of the building. The locations and details of the detection range and accuracy of the accelerometers and pressure transducers used in this study are listed in Table 1. The acceleration signals were recorded in the same manner with that for the wind pressure signals.

2.3. Typhoon Haima

Typhoon Haima was one of few tropic cyclones that have made landfall in Shenzhen at a typhoon strength level over the last decade. According to the information released by Cooperative Institute for Meteorological Satellite Studies (CIMSS) Tropical Cyclones, as shown in Fig. 3, Haima formed as a tropical depression over the Western North Pacific at 18:00 of 14 October 2016 (Coordinated Universal Time (UTC); Beijing Time = UTC + 08:00), then intensified into a typhoon on 15 October and followed a northwesterly track towards the South China Sea, then made landfall over the coastal area in Shenzhen on 21