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Non-Gaussian characteristics of wind pressures on a 600-m-high skyscraper during Super Typhoon Mangkhut

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SUMMARY:
This paper investigates the non-Gaussian characteristics of wind pressures on the facades of a 600-m-high skyscraper measured by 48 pressure transducers during Super Typhoon Mangkhut. Due to the remarkable intensity of the super typhoon (i.e., 10-min mean wind speed atop building reaching 47.3 m/s), the non-Gaussian characteristics of extremely low negative cladding pressures (i.e., 10-min mean value below -0.6 kPa) on the side and leeward facades are investigated in this paper. The most prominent non-Gaussian features were observed on the downstream building facades when the winds approached the monitored skyscraper diagonally. Moreover, the bimodal distribution of the wind pressures on the windward face at the lower floor was found, which was attributed to the interference effect from surrounding buildings. This paper aims to enhance the understanding of wind pressure characteristics of the cladding of supertall buildings under severe wind conditions, and therefore provide useful information for the wind-resistant design of future skyscrapers.

Keywords: field measurement, wind pressure, non-Gaussian characteristics, super typhoon

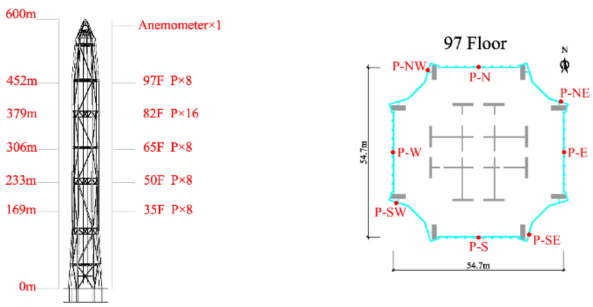
1. INTRODUCTION

Wind pressures on the claddings of high-rise buildings are of great importance to their wind-resistant design. Although the atmospheric boundary layer winds can be regarded as Gaussian processes, non-Gaussian characteristics are observed from cladding pressures (Peterka and Cermak 1975; Holmes 1981). Hence, utilizing a conventional Gaussian model in cladding designs may underestimate peak wind pressures, even result in cladding damages. Most previous studies investigated the non-Gaussian characteristics of cladding pressures through wind tunnel testing with scaled models or numerical simulations, yet the wind pressures directly measured on the claddings of full-scale prototype supertall buildings were seldom reported, not to mention those obtained under extreme wind conditions such as tropical cyclone events. In this paper, the non-Gaussian features of cladding pressures are investigated based on the field measurements on a 600-m-high skyscraper during Super Typhoon Mangkhut.

2. MONITORED SKYSCRAPER AND SUPER TYPHOON MANGKHUT

With height of 600 m, the monitored skyscraper is currently the fourth tallest building in the world and the second tallest in China. It is in the densely built-up urban area of Shenzhen, a typhoon-prone coastal city. To monitor the conditions of structural safety and serviceability under violent wind excitations, a comprehensive structural health monitoring (SHM) system integrated by various sensors has been implemented in the skyscraper (Li et al. 2018). With the aim to investigate the wind pressures on the cladding of the monitored building during a typhoon event, this paper utilizes the field measurements during Super Typhoon Mangkhut collected by an ultrasonic anemometer and 48 wind pressure transducers of the SHM system (Shown in Fig. 1).

Super Typhoon Mangkhut (1822) triggered the highest typhoon alert (i.e., Red Alert) in China, and it was regarded as the most powerful typhoon hit Shenzhen since 1946. Following the northwesterly path illustrated in Fig. 2, Mangkhut reached its closest location from the monitored building with approximately 130 km around 14:00 on 16 September 2018 (abbreviated as 14:00/16 herein). This paper analyzes the 24-hour-long field measurements starting at 00:00/16, which covered the period when Mangkhut exerted the greatest impact on the skyscraper. As shown in Fig. 3**,** the 10-min mean wind speed atop the monitored building peaked at 47.3 m/s around 14:20/16. The 10-min mean wind directions were approximately stable at 90° from 12:00/16 to 15:00/16.



(a) Elevation layout (b) Floor plan

Figure 1. Arrangement of sensors ("P" - pressure transducer)

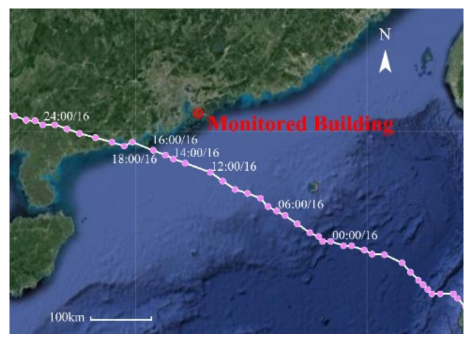


Figure 2. Path of Super Typhoon Mangkhut

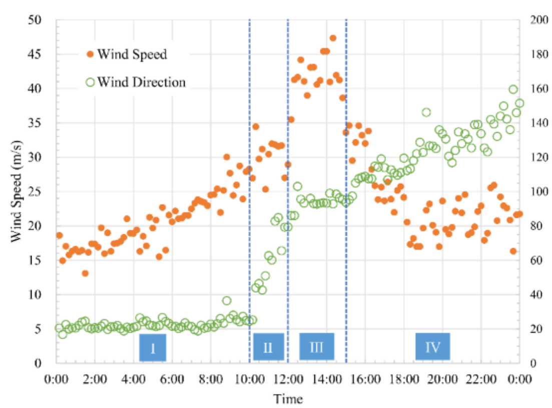


Figure 3. 10-min mean wind speed and direction

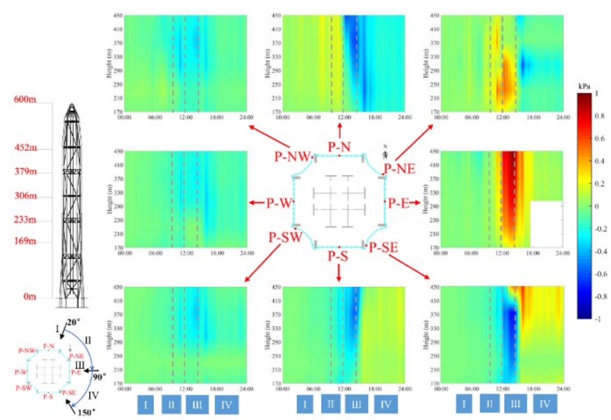


Figure 4. Distributions of cladding pressures

3. NON-GAUSSIAN CHARACTERISTICS OF WIND PRESSURES

3.1. Time histories and distributions of wind pressures

The variation and distribution of 10-min mean wind pressures during Mangkhut are illustrated in

Fig. 4. From Figs. 3 and 4, it can be readily observed that the variation of the wind pressures with wind speed and direction. The instantaneous extreme positive and negative pressures reached 2.11 kPa and -2.56 kPa during Mangkhut, respectively.

3.2. Non-Gaussian characteristics

The non-Gaussian characteristics are usually quantified by skewness and kurtosis values, which describe the asymmetry and peakedness of a probability density distribution (PDD), respectively. A Gaussian PDD corresponds to the skewness of 0 and the kurtosis of 3, and the deviations from these values reflect the extent to which a PDD differs from a Gaussian distribution. This study firstly selects the wind pressures measured by four transducers (i.e., P-N, P-E, P-S, and P-W) at the height of 452 m (97th Floor) to investigate their non-Gaussian features. It is reasonable to assume that the wind pressures measured at such altitude were not under wind interference effects caused by other buildings in proximity which are generally less than 220 m in height. Figs. 5(a) and (b) plot the skewness and kurtosis values against the mean wind pressure (denoted by $\bar{p}$) of each 10-min-long measurement segment, respectively, while Figs. 5(c) and (d) plot those values against the peak pressure ($\hat{p}$), receptively. The non-Gaussian characteristics are readily observed in the measurements by P-N, P-S, and P-W. And it is found that the non-Gaussian characteristics of negative wind pressures strengthen as the mean pressure decreases. Particularly, the most prominent non-Gaussian characteristics (skewness and kurtosis reached almost -3 and 17, respectively) were observed when $\bar{p} = -0.2$ kPa and $\hat{p} = -0.5$ kPa. To investigate the mechanism behind these prominent non-Gaussian features, Fig. 6 plots the PDD of the 10-min-long Data Segment 1 (indicated in Fig. 5) at P-N, which was recorded during Period IV when the winds approached from the southeast (i.e., "SE-NW" diagonal axis of the building section). As shown in the figure, the PDD agrees well with a Gumbel distribution. It is believed that the non-Gaussian characteristics of the wind pressures on the downstream north facade were caused by the vortex shedding generated from the building northeast corner.

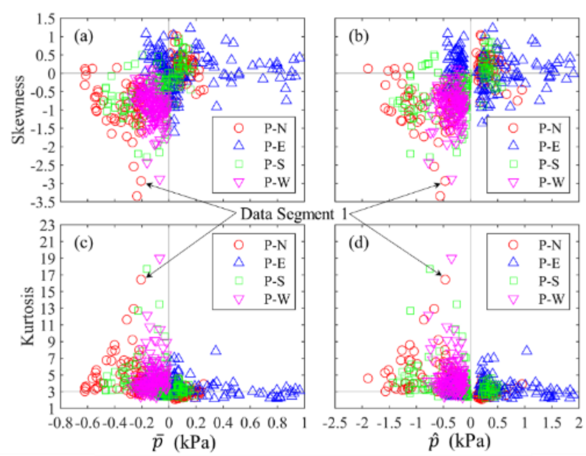


Figure 5. Non-Gaussian features of cladding pressures

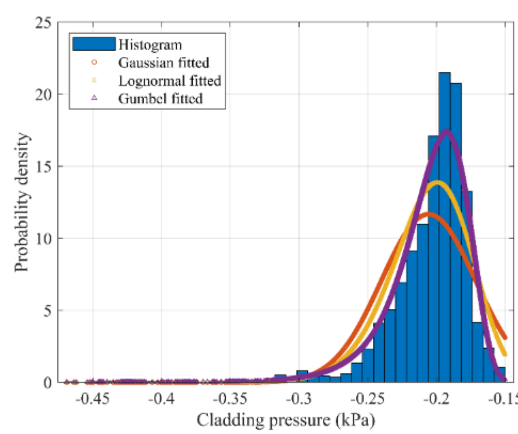


Figure 6. PDD of Data Segment 1

3.3. Bimodal distribution

According to Liang et al. (2020), the interference effect of surrounding buildings could lead to non-Gaussian distribution of wind pressures on the cladding of downstream buildings. Since there are two tall buildings (over 200 m) to the east side of the monitored skyscraper and the height of

35F is 169 m, the interference effect may significantly affect the wind pressure distributions on the cladding of 35F under east wind. Fig. 7 presents the PDD of the wind pressures on the windward face at 35F. It can be observed in the figure, the bimodal distribution (Norm + GEV) agrees well with the field measurements. This indicates that the bimodal distribution can be used to describe the PDD of the wind pressures on the windward face under interference effect from surrounding buildings.

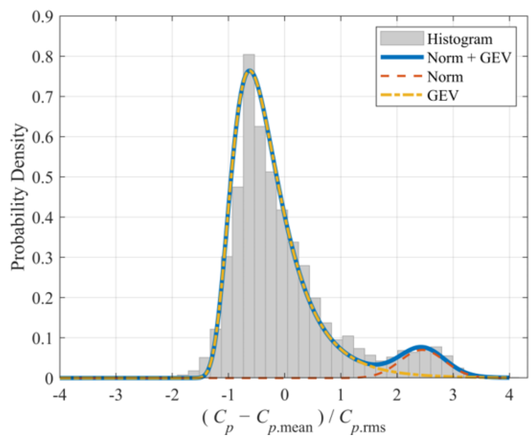


Figure 7. Bimodal distribution of cladding pressures

4. CONCLUSIONS

This paper investigated the non-Gaussian characteristics of wind pressures on the cladding of a 600-m-high building measured during Super Typhoon Mangkhut. The measurements showed that, at the higher floor (e.g., 97F), the non-Gaussian features of the wind pressures on the side and leeward facades were significant. In particular, the most prominent non-Gaussian features of the wind pressures occurred on the downstream facades when the winds approached the building diagonally. At the lower floor (e.g., 35F), a bimodal distribution of the wind pressure on the windward face was observed, which was attributed to the interference effect from surrounding buildings. It is suggested to consider these non-Gaussian characteristics of wind pressures in the wind-resistant cladding design of high-rise buildings in typhoon-prone regions.

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