Wind Profile Observations in Tropical Cyclone Events
Using Wind-Profilers and Doppler SODARs

K.T. Tse, S.W. Li, P.W. Chan, H.Y. Mok, A.U. Weerasuriya

1Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong.

Abstract

The typhoon wind measurements taken during 2007-2009 in Hong Kong by wind-profilers and Doppler SODARs are unitized to calculate both the hourly mean and 10-min mean wind profiles. The mean wind profiles are then fitted to an empirical model taking into consideration the super-gradient feature, the log-law and the power-law. The results show that the super-gradient feature, which is commonly observed for typhoon winds over the sea, is not obvious in the mean wind profiles investigated. Wind tunnel tests are planned to perform afterwards as follow-ups to investigate the topography influencing the mean typhoon wind profiles observed.

1 Introduction

Mean wind profiles in the typhoon boundary layer are important in the fields of both meteorology and wind engineering. For meteorology, the knowledge of the mean typhoon boundary layer wind profile is critical to understand the overall dynamics of tropical cyclones since it implicitly reflects air-sea momentum exchange characteristics (Powell et al., 2003). For wind engineering, mean typhoon wind profiles in the lower portion of the atmospheric boundary layer, below the height of 1000m, determine the wind loads acting on structures built in hurricane-prone regions. While the log-law and power-law are universally used to describe the vertical variation of the mean wind velocity with height below the gradient height, Vickery et al. (2009) found that the log-law is inadequate to describe the mean typhoon wind profile in the entire typhoon boundary layer. Actually, Vickery et al. (2009) introduced an empirical function to describe the mean typhoon wind profile. Although this empirical function successfully modeled the super-gradient feature observed in the typhoon boundary layer, it is only applicable to describe typhoon winds over the sea, and therefore its applicability to describe the typhoon winds over land needs to be further investigated.

Hong Kong is situated on the south east coast of the Asian continent facing the South China Sea. On average, there are 12 tropical cyclones appeared over the South China Sea each year and 6 to 7 of them moved close to or across Hong Kong. Since typhoons frequently occur, Hong Kong is a convenient location for studying tropical cyclone winds. Using wind measurements taken by wind-profilers and Doppler SODARs, the local mean typhoon wind profiles are calculated during the passages of several typhoons. In an attempt to evaluate the applicability of the empirical profile

1 Corresponding author: E-mail address: timkttse@ust.hk; Tel.: +852 23588763; fax: +852 23581534. Mailing address: Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
function introduced by Vickery et al. (2009), the mean wind profiles calculated are then fitted to the empirical profile function suggested by Vickery et al. (2009), the log-law and the power-law. Since the turbulence time scale of typhoon winds is not well understood (Yu et al., 2008), both the hourly mean wind speed (Canadian Code) and the 10-min mean wind speed (Chinese Code) are calculated. In addition to analyzing the weather station observations, wind tunnel tests are planned to be performed to investigate the influence of topography surrounding the weather station in question on the mean wind profile analyzed previously in a controlled environment.

2 Data and Processing Methodology

The wind measurements taken by the Siu Ho Wan (SHW) station during the passages of typhoons from 2007 to 2009 are selected and processed. The geographic location of the SHW station is 22°18′21″ latitude and 113°58′45″ longitude. Wind measurements taken by both the Doppler SODAR and the wind-profiler are unitized to calculate the mean typhoon wind profiles.

By synchronizing the wind measurements taken by the Doppler SODAR and the wind-profiler, two types of mean wind velocities are calculated and discussed, namely the hourly mean and 10-min mean. To ensure that only the wind measurements taken during the typhoon passages are selected, the tropical cyclone report prepared by the Hong Kong Observatory is referenced. For a given typhoon, the moment at which the Hong Kong Observatory issued No.1 warning signal is taken as the start moment, and the moment at which the Hong Kong Observatory cancelled all warning signals is taken as the end moment. To ensure the mean profiles calculated are from the typhoon wind field, the wind measurements taken below 500 m are averaged to calculate the Mean Boundary Layer (MBL) wind, and only profiles showing the MBL wind larger than 10m/s are considered. In addition, following the MBL wind philosophy, the MBL wind direction is calculated and only profiles showing the MBL wind direction in the range of (225°, 360°) or (0°, 45°) are selected to ensure the influence of land topography is minimal.

The empirical profile function provided by Vickery et al. (2009), the log-law and the power-law, which are listed in order below, are used to fit the observed mean typhoon wind profiles.

\[
U(z) = \frac{U_10}{(z/10)^\alpha} \quad (1)
\]

\[
U(z) = u_r/k \ln(z/z_0) - u_r/ka(z/H^*)^n \quad (2)
\]

\[
U(z) = u_r/k \ln(z/z_0) \quad (3)
\]

3 Observation Results and Discussion

3.1. The Hourly Mean Wind Profiles

The hourly mean wind profile measured during the period of Typhoon Fengshen (2008) and the fitted model profiles are shown in Fig. 1. As indicated by the figure, the observed hourly mean wind profile appreciably fluctuates around the model profile predicted by both equation (1) and by conventional models (the log-law and the power-law). It can be found from Fig. 1 that the super-gradient phenomenon is not exhibited and the empirical profile function introduced by Vickery et al (2009) does not outperform the conventional models (the log-law and the power-law).
3.2. The 10-min Mean Wind Profiles

A typical 10-min mean wind profile and the fitting results are presented in Fig. 2. While the hourly mean wind profile shown in Fig. 1 indicates that the wind velocity increase monotonically with height, the 10-min mean profile shown in Fig. 1 indicates there is a super-gradient wind at a height below 500 m. As in our analysis comparing the 10-min mean wind profiles from different periods of time during the visit of Typhoon Fengshen (2008), this difference can be not explained by long-term typhoon wind characteristics, the influence of surrounding topographies and the wind strength. Therefore, the difference can only be explained by wind velocity fluctuations in the upper portion of the atmospheric boundary layer (above 300 m) with time scales longer than 10 minutes.

4 Wind Tunnel Tests

To further investigate the influence of surrounding topographies of the SHW station on the mean wind profile discussed above, a topography study using wind tunnel test techniques are planned to be carried out. We are planning to conduct a series of wind tunnel tests to simulate the wind flow above
the SHW station under the condition that the oncoming wind flows are different in order to identify the influence of the topography surrounding the SHW station on the mean wind profile observed during typhoon events. Using the findings made in the wind tunnel tests, the discussions on the mean wind profile presented above will be extended.

References

