Wind characteristics near bridge during strong typhoon procedures

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Abstract

In recent years, the southeast coastal areas are frequently influenced by strong typhoon. Based on the data of typhoon Muifa (Muifa 1109) measured by the bridge health monitoring system, the wind fluctuating characteristics of two places were analysed. The characteristics, such as turbulence intensity (TI), turbulence scale (TS), gust factor (GF), distribution of fluctuating wind, were mainly discussed. The results show that before and after typhoon landing TI is scattered than it during typhoon. Lateral TI is greater than longitudinal TI (\( T_{L} = 1.011 T_{L} \) ) at 205.5m, so value according the Standard is bad for the wind resistance of bridge. TSs are larger than the Standard, especially lateral value (larger by 16.4%). Fitting curve of GF changing with TI is under Ishizaki curve and above Choi curve & Cao fitting curve.

Introduction

Typhoon is one of several major natural disasters in China, causing certain economic losses and casualties every year and threatening the sustainable development of coastal areas. The eastern coastal areas in China is a powerful typhoon landing area frequently. According to incomplete statistics, there are about 82 times typhoon that had great influence to Shanghai from 1949 to 2005. But because of the particularity and complexity of the typhoon, it is difficult for wind tunnel laboratory to have a precise simulation. So field measurement becomes an effective means of research [1].

Many scholars have carried out the experimental studies: to typhoon Tamura [2] has done the simulation analysis of the typhoon observed from a Nagasaki observation tower, it is concluded that the typhoon turbulence intensity is 30% higher than good state climate and gust factor in high wind speed (\( > 20 \text{ m/s} \)) is bigger than good state climate; Qiu-sheng Li [3] analysed typhoon characteristics using the data 2.86km away from the typhoon eye landing point of typhoon Hagupit (0814), it is concluded that wind characteristics (such as gust factor, turbulence intensity and integral scale) before typhoon are significantly larger than after landing. Using the measured typhoon data, Ishizaki [4] gave experimental formula between typhoon gust factor and turbulence scale. Then, Choi [5] revised Ishizaki formula and Sharma [6] fit out the conversion relation between gust factor and turbulence intensity of typhoon from Australian environment using experimental typhoon data. Cao [7] observed typhoon Maemi (0314) using the ultrasonic anemometer installed on the Japanese island of Okinawa, it is concluded that the typhoon power spectrum can be expressed by Von Karman - power spectrum function.

Due to great variability and significant regional characteristics of strong typhoon, whether the above research conclusion can be accurately applied to the southeast coastal areas in China is not clear. Typhoon Muifa is not directly across the long-span Bridges, but in fact, the impact on the bridge is very great. To research typhoon Muifa, a powerful typhoon, it can provide a powerful typhoon wind field for the study of the Bridges and buildings and it is beneficial to promote the development of the refinement of bridge wind vibration theory.
Anemometer and typhoon Muifa

Anemometer

Test data is from health monitoring system of Shanghai Yangtze River Bridge which is located in the Changjiang river between Chongming and Changxing island. According to the wind resistance design code in China, the surrounding terrain of the observation position should belong to A class. Four anemometers are as follows: two for two main channel bridge towers (number SWS1401, SWS1402 respectively, the level height is 215.7 m), two for the upward side and down side of the midspan bridge deck (number SWS1201, SWS1202 respectively, the level height is 70.2 m). Through the Shanghai Yangtze waterway administration official website [8], water level changed over time, but kept in about 3.2 m. In order to simplify the calculation, water level is taken as a constant value (3.2m). The height of stormy waves changed with distance from typhoon and the strength of wind speed. This paper refers to the result of Xiao-bin Chen [9] on Yangtze River during period of typhoon Muifa (1109). In order to simplify the calculation, it is taken as 7m (fixed value). Thus the calculated height of the two points are 60 m and 205.5 m respectively (the following referred to the calculation height without special description) and the horizontal distance is 365 m, as shown in figure 1. The sampling frequency of anemometer is 4 hz, wind angle defined the north is 0°, clockwise rotation, so the east is 90°. Considering the symmetry of the structure of the bridge, this paper mainly studied the measured results of two anemometers, SWS1201 and SWS1401 respectively.

Fig.1 Layout of sensors on the bridge (Unit: m)
Typhoon Muifa

Typhoon Muifa, known in the Philippines as Typhoon Kabayan, was a large, strong and persistent typhoon which affected a number of countries in the Pacific, killing 22 and causing widespread damage worth US$480 million. It was the ninth named storm, third typhoon and the second super-typhoon of the 2011 Pacific typhoon season.

The low-pressure area which became the typhoon originally formed on 23 July. It gradually drifted to the west, becoming a tropical depression. As it turned north and neared the Philippines it rapidly strengthened, becoming a Category 5 typhoon on the Saffir-Simpson Hurricane Scale (SSHS). In the Philippines, the storm claimed eight lives and caused much damage. The system brought down trees; the northeast Philippines experienced strong winds and heavy rains, leaving motorists stranded on several roads and expressways. Muifa also sank a Malay ship with 178 passengers. The system then drifted north, weakening steadily until it curved to the west and threatened Micronesia. The typhoon hit Okinawa, Japan with 41 inches of rain, flooding the small island and injuring 37 people in a 30-hour period. The storm disrupted air travel, leaving 13,630 people stranded on the island. The system then steadily drifted west, nearing Taiwan and prompting emergency warnings and high alerts; however, the storm missed the island. The typhoon moved further west towards mainland China, causing thousands to flee from their homes. A level-4 high-wave warning was issued, and some 11,000 rescue workers mobilized in 120 teams.

Map plotting the track and intensity of the storm according to the Saffir–Simpson hurricane wind scale. A parade of low-pressure areas and tropical disturbances formed from the Intertropical Convergence Zone late on July 15. Late on July 23, one of the last low-pressure systems developed further to a weak tropical disturbance, which formed southeast of Chuuk in Micronesia. The system drifted to the west, and on July 25 the Joint Typhoon Warning Center (JTWC) upgraded the low-pressure area to a tropical depression. At that time, it was located approximately 505 nautical miles (935km; 581mi) west of Guam. At midnight that day, the JMA began monitoring the system as a tropical depression. Early on July 28, the JTWC upgraded the system to a tropical storm. A few hours later the JMA also upgraded the system to a tropical storm, naming it Muifa. Also on 28 July, the storm entered the Philippine Area of Responsibility (PAR); the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) named it Kabayan. The storm drifted north over the next day, while maintaining tropical-storm strength. On the night of July 29, Muifa was upgraded to a severe tropical storm. Overnight, the storm strengthened rapidly and was upgraded to a typhoon the next morning. According to the JTWC, Muifa had strengthened from a tropical storm to a super typhoon in less than 24 hours; it reported that the storm was reaching one-minute sustained wind speed of 140 knots (260 km/h; 160 mph). However, the typhoon weakened later in the day.

According to the JTWC, on July 31 the typhoon encountered an upper-level trough and weakened to a category-4 typhoon on the SSHS. The system gradually moved north, then turned west and drifted towards Okinawa before turning northwest again (when it was finally downgraded to a tropical storm by the JTWC). Soon afterwards, the JMA downgraded Muifa to a severe tropical storm. After weakening to a tropical storm, Muifa made landfall at the estuary of the Yalu River on August 8 and the JTWC issued its final warning. Early on August 9, Muifa weakened to a tropical depression in northeast China and later became a low-pressure area.
The maximum typhoon influence on observation position appeared at 8 on August 7, 8. At this time the typhoon center was located in north latitude 31.8° and 124.4° east longitude, the largest wind was level 13 (40 m/s), minimum pressure was 960 mpa (see figure 2). Typhoon Muifa (1109) affected bridge up to 24 hours, causing traffic closed 11 hours. In order to compare the before and after the typhoon maximum and typhoon maximum features, a total of 42 hours data was selected, from 8:00 August 6 to 2:00 August 8, the path of typhoon Muifa was shown in figure 2.

**Wind characteristics of typhoon**

**Mean wind speed and wind direction**

The data collected from anemometer is under the polar coordinate wind speed S and the azimuth β. Decomposing to the rectangular coordinate system, the north-south direction wind speed time history \( u_x \) and the east-west direction wind speed time history \( u_y \) can be gotten. By 10 min as the basic interval, calculating average wind speed, first calculate the average wind speed \( \bar{u}_x, \bar{u}_y \), and then calculate the average velocity \( U \), namely

\[
U = \sqrt{\bar{u}_x^2 + \bar{u}_y^2} \quad (1)
\]

According to the relationship between the original rectangular coordinate system, the main wind direction Angle can be obtained by formula:

\[
\phi = \begin{cases} 
\arccos \frac{\bar{u}_x}{U} & \bar{u}_y > 0 \\
360^\circ - \arccos \frac{\bar{u}_x}{U} & \bar{u}_y < 0 
\end{cases} \quad (2)
\]

Figure 3 and figure 4 are 10-min average wind speed changing with time and the main direction changing with time, respectively.
From figure 3, 10-min average wind speed for 60m and 205.5m reach to the maximum at the same time in, 27.0m/s and 33.5m/s, respectively, and the main wind direction angle 332° and 323°, respectively. For the small differences of wind direction, the main reason for this difference is caused by different measuring point of the horizontal position and height.

The fluctuation component of the wind

Turbulence intensity

Turbulence intensity is the characterization of the flow fluctuation index. Because the fluctuating wind has 3-d feature, the evaluation index of turbulent intensity has a total of three indexes, including along, horizontal and vertical turbulence intensity. Due to along wind direction and horizontal direction of the wind characteristics is more important to the bridge structure, along and horizontal turbulence intensity are calculated according to the formula (3), shown in figure 5.

\[
I_u = \frac{\sigma_u(z)}{U(z)}; \quad I_v = \frac{\sigma_v(z)}{U(z)}
\]  

(3)

Here, \(\sigma_u(z)\), \(\sigma_v(z)\) are the along and horizontal wind speed standard deviation of z place, respectively. Below figure shows the changing situation between wind direction and along and horizontal wind turbulence intensity.
From figure 5, turbulence intensity decreases with the increase of height, but horizontal wind turbulence intensity changes less significantly than along direction. Turbulence intensity is more scattered before and after the typhoon maximum speed, and is relatively stable near maximum speed. Because of the existence of this phenomenon, the most unfavorable situation may not appear at the biggest wind speed when study the wind-induced vibration of a bridge.

**Turbulence integral scale**

Fluctuating wind speed can be taken as a superposition of different frequency and cycle component, or can be intuitive thought as combination of different size of vortexes whose average value are known as turbulence integral scale. In practical application, the expression of turbulence integral scales are as follows:

\[
L^u_a = \int_0^\infty R_a(\tau) d\tau / \sigma^2_a : \tau = \tau / U
\]

Among them, \(a = u, v, w\). \(R_a(\tau)\) is autocorrelation function of different time at same point. Due to the three dimensional nature of fluctuating wind, the three directions of fluctuation component corresponds to a total of nine integral scales. The along and horizontal 10-min turbulence integral scale of the fluctuating wind in the \(x\) direction (\(L^x_a\) and \(L^x_b\)) are calculated, as shown in figure 6.
From figure 6, at 60m, the average of $L_u^x$ and $L_v^x$ are 143.2m and 85.4m, respectively, and the relation between $L_u^x$ and $L_v^x$ is $L_v^x = 0.596L_u^x$. At 205.5m, the average of $L_u^x$, $L_v^x$ are 211.8m and 121.7m, respectively, and the relation between $L_u^x$ and $L_v^x$ is $L_v^x = 0.596L_u^x$.

**Gust factor**

Wind intensity of fluctuation can also use gust factor to represent. Gust factor $G(t_g)$ is defined as the ratio between maximum average wind speed for time of duration $t_g$ (wind duration time is generally taken as 3s in the structure wind engineering, so in this article $t_g$ is taken as 3s) and the average wind speed for basic time interval:

$$G_u(t_g) = 1 + \frac{\max(\bar{u}(t_g))}{U}$$  \hspace{1cm} (5)

Here, $\bar{u}(t_g)$ is the average value of along fluctuating wind for a set period of time $t_g$.

Through calculation, $G_u$ are in average of 1.254 and 1.192 at 60m and 205.5m, respectively, with good fitting to the results of Wang [10]. Study shows that there is a certain difference for the gust factor before and after the peak average wind speed, as shown in figure 7.

Fig. 7 Variation of gust factor at different speed
From figure 7, we can see that different rules between $G_u$ and wind speed exist for two different $G_u$: before maximum wind speed, $G_u$ decreases with the increase of wind speed, and in line with the simulated formulation $G_u = 1.904\times(1 + U)^{-0.137}$ at 60m; but $G_u$ keeps in the vicinity of 1.235, decreasing slightly with the increase of wind speed at 205.5m. After maximum wind speed, $G_u$ keeps in the vicinity of 1.183, decreasing slightly with the decrease of wind speed at 60m; $G_u$ decreases with the decrease of wind speed, and in line with the simulated formulation $G_u = 0.879\times(1 + U)^{0.086}$ at 205.5m. This rule is unique to typhoon Muifa, and further research is needed for this conclusion. Using the statistical method to establish the relation between turbulence intensity and gust factor is concerned by wind engineering field, and Ishizaki [4] and Choi [5] suggested that the functional form is as flowing

$$G(t) = 1 + k_1 \times t_k^2 \ln\frac{T}{t}$$  \hspace{1cm} (6)

Here, $T$ is average time interval, $t$ is the gust wind continuous interval, and $k_1, k_2$ are two undetermined parameters.

![Figure 8 Variation of gust factor at different turbulence intensity](image)

**Table 1 Comparison of $k_1$, $k_2$ fitting result**

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**Probability distribution**

Fluctuating wind speed distribution function is commonly used gaussian distribution to describe, but under the certain condition of typhoon, fluctuation wind speed is also subject to gaussian distribution becomes very valuable research. Following are the results of wind speed probability density distribution function research for two height, as shown in figure 9.
From figure 9, fluctuating wind distribution is in line with the gaussian distribution, the probability density distribution function is in the form of \( y = y_0 + \frac{A}{\omega \sqrt{\pi/2}} e^{-2(x-x_0)^2/\omega^2} \). The center of the distribution function is near the average wind speed, with small deviation.

**Conclusion**

Typhoon Muifa has strong regionality and particularity, the deep research of Muifa can provide basis for long-span bridges wind resistance analysis under the action of a strong/typhoon, can also provide the important material of the typhoon database for east China coastal areas.

Turbulence intensity is more scattered before and after the typhoon maximum than typhoon maximum, the most unfavorable situation may not appear at the biggest wind speed when study the wind-induced vibration of a bridge.

Fluctuating wind distribution is in line with the gaussian distribution and the center of the distribution function is near the average wind speed.

**References**


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