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# Wind Characteristics and Response of a Long-Span Bridge During Direct Attack of a Strong Typhoon

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**SUMMARY:**
Most long-span bridges along coastal region of China have not been direct attacked by strong typhoon winds. The performance of these structures during the direct attack of strong typhoon wind has not been well clarified. The wind and deck vibration data of Xihoumen Bridge during the direct attack of a strong typhoon are captured by the structural health monitoring system. The mean and turbulence wind characteristics as well as the response of the bridge deck are analyzed in this study. The turbulence intensity, integral scale length and angle of attack are found to be significantly different from the specifications suggested by current code. The response of the bridge deck is positively correlated to the mean wind speed, but could also be affected by the turbulence parameters, angle of attack and dynamic characteristics of the bridge. The findings in this study provide some new understandings of typhoon-induced vibration of long-span bridges.

*Keywords: Long-span bridge, Strong typhoon, Wind characteristics*

## 1. INTRODUCTION

Continuous advancements of design theory, new materials and construction techniques enable more and more long-span cable-supported bridges to be designed and constructed. The low flexibility and damping ratio make these flexible structures very sensitive to the wind effects. For these long-span bridges located at coastal regions, they are exposed to a high chance of attacking by strong typhoon winds. However, most long-span bridges along coastal region of China were completed and in service for a relatively short period, which have not been direct attacked by strong typhoon winds. The performance of these structures during the direct attack of strong typhoon wind has not been well clarified.

In typhoon boundary layer, the wind is featured with high turbulence intensity (Cao et al., 2009), low-level jet (Fang et al., 2022) and large angle of attack (Li et al., 2016). These wind characteristics are not well involved in current codes or standards. The in-situ measurement data, including the typhoon wind and real response of the structure captured by the structural health monitoring system are greatly helpful to enhance the understanding of typhoon-induced vibration of long-span bridges. It will also be beneficial to update the code before designing longer-span bridges located at typhoon-prone regions. This study analyzes the wind characteristics and bridge deck response of Xihoumen bridge during the direct attack of a strong typhoon captured by the structural health monitoring system.

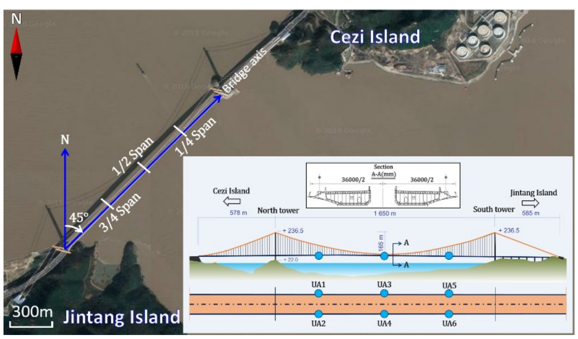
## 2. DESCRIPTION OF MEASUREMENT SYSTEM

### 2.1. Xihoumen Bridge and Health Monitoring System

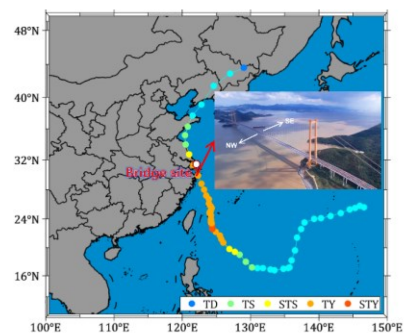
Xihoumen Bridge (121°54' E, 30°03' N) is a central slotted steel box girder suspension bridge with main span of 1650m. The structural health monitoring system (SHMS) of Xihoumen Bridge is equipped with six 3-D ultrasonic anemometers (UA1-UA6) at the mid- and quarter- span, whose wind speed range is 0-65m/s and maximum sampling frequency is 32Hz, as shown in Figure 1(a). The three directions ($x$, $y$, and $z$) of the anemometer's body axis coordinate correspond to true north, west, and vertical, respectively. Besides the anemometers, 12 unidirectional servo-type accelerometers are also arranged along the bridge girder, whose maximum sampling frequency is 100Hz.

### 2.2. Typhoon Muifa

Strong Typhoon Muifa (2212) formed on 8th September 2022 (UTC time), and made its landfall in Zhoushan, Zhejiang province on 14th September. It is the strongest Typhoon landing in Zhoushan since 1949. And then, the typhoon made its second, third and fourth landfall in Shanghai, Shandong and Liaoning. More than 1.2 million people were forced away from their homes on account of this storm. During its moving on China mainland, the maximum gust wind speeds reach 53.6m/s. Typhoon Muifa directly passed through Xihoumen Bridge with the shortest distance from the storm center within 20 km, as shown in Figure 1(b).



(a) Arrangement of bridge and the SHMS



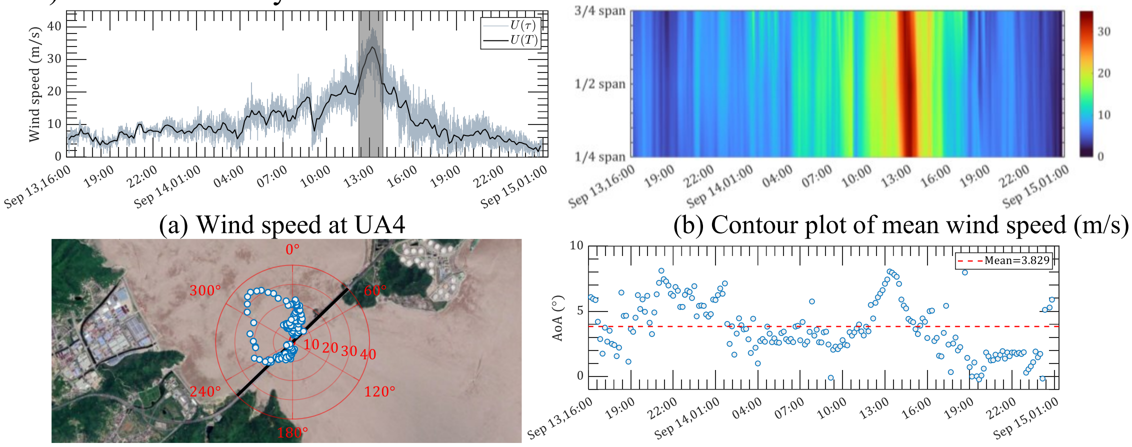
(b) Typhoon track

**Figure 1.** Measurement system in Xihoumen Bridge (TD: Tropical depression (10.8~17.1 m/s), TS: Tropical storm (17.2~24.4 m/s), STS: Strong Tropical storm (24.5~32.6 m/s), TY: Typhoon (32.7~41.4 m/s), STY: strong typhoon (41.5~50.9 m/s))

## 3. WIND CHARACTERISTICS

### 3.1. Mean wind speed and direction

The wind speed captured by UA4 sensor at midspan is plotted in Figure 2(a). The maximum gust wind nearly reaches 40 m/s. The contour plot of 10-min mean wind speed is plotted in Figure 2(b) using the data captured by UA2, UA4 and UA6. The wind speed increases rapidly at 04:00, Sep 14, and almost reaches 34m/s at 13:00, Sep 14. The storm sustained until Sep 14, 19:00. Figure 2(c) shows the wind rose captured by UA4, suggesting that the strong winds are almost perpendicular to the bridge. The angle of attack (AOA) at UA4, which is defined as the angle between the mean wind velocity vector and the horizontal plane, is shown in Figure 2(d). significant variation of AOA can be found during the storm. Many of them exceeds the scope $(-3°\sim 3°)$ recommended by current code with the mean value of $3.8°$ and maximum of $8°$.



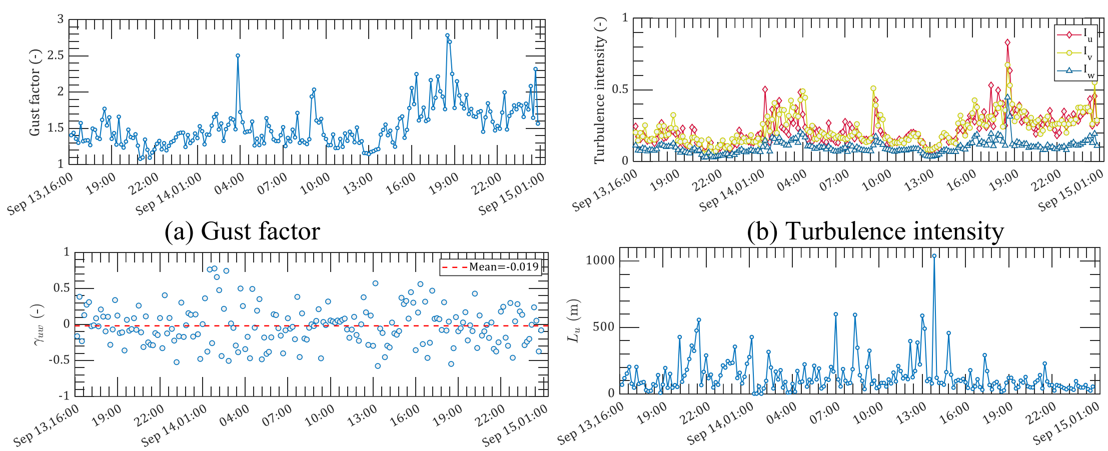

(a) Wind speed at UA4 (b) Contour plot of mean wind speed (m/s)

(c) Wind rose at UA4 (d) Angle of attack at midspan (UA4)

**Figure 2.** Mean wind speed and angle of attack

### 3.2. Turbulence characteristics

The turbulence parameters, including the gust factor, turbulence intensity, cross-correlation coefficient and integral scale length are shown in Figure 3. It can be seen that the gust factor varies dramatically. A sudden increase can be noted both for gust factor and turbulence intensity around Sep 15, 00:00. The cross-correlation coefficient for *u*-*w* turbulence $\gamma_{uw}$ varies with time between -1 and 1 with the mean of -0.019. The mean values of integral scale length for $L_u$: $L_v$: $L_w$ are 134.705m,132.447m and 34.740m, respectively.



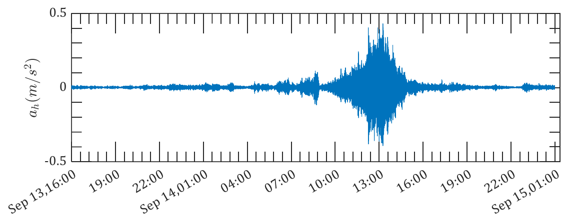

(a) Gust factor (b) Turbulence intensity

(c) Cross-correlation coefficient (d) Integral scale length

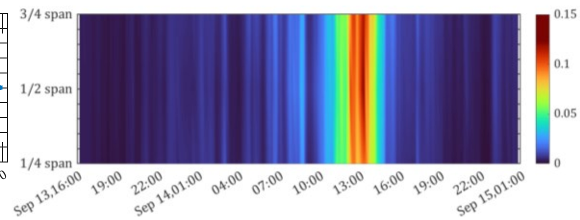
**Figure 3.** Turbulence characteristics at midspan (UA4)

## 4. BRIDGE RESPONSE

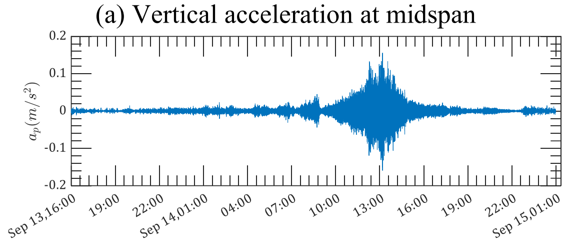
The vibration accelerations of the bridge deck in vertical, lateral and torsional directions are shown in Figure 4. The vibration is very small before Sep 14,04:00, where the wind speeds are relatively low. The amplitude of vibration increases with the rapidly growing wind speeds, and then reaches maximum around Sep 14, 13:00 where the mean wind speed exceeds 33.89m/s. The vertical response at mid-span is larger than the counterparts at quarter-span, while opposite phenomenon can be found for torsional response, suggesting that the prevailing vertical and torsional vibration modes of bridge deck are symmetric and antisymmetric, respectively.



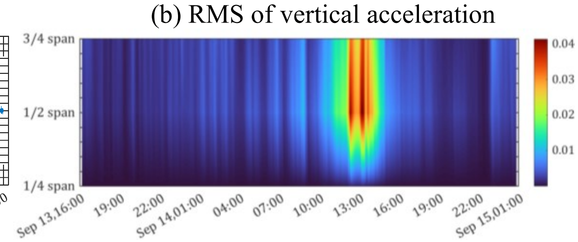

(a) Vertical acceleration at midspan



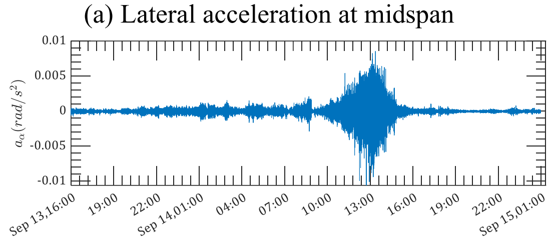

(b) RMS of vertical acceleration



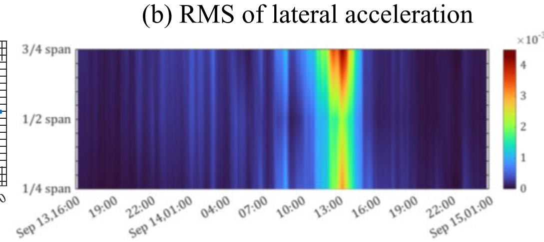

(a) Lateral acceleration at midspan




(b) RMS of lateral acceleration




(a) Torsional acceleration at midspan




(b) RMS of torsional acceleration

**Figure 1.** Example of figure.

## 5. CONCLUSIONS

The wind characteristics and bridge deck response of Xihoumen bridge during the direct attack of a strong typhoon were captured and analyzed in this study. The wind characteristics are found to be significantly different from the specifications suggested by current code. The response of the bridge deck is positively correlated to the mean wind speed, but could also be affected by the turbulence parameters as well as the angle of attack. The prevailing vertical and torsional modes of bridge deck during the passage of the storm are symmetric and antisymmetric, respectively.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