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Wind field characteristics at the Outdoor Experimental Base for Bridge Wind Engineering

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SUMMARY:
Recently, a new experimental method was proposed for the wind engineering research of bridges, i.e., studying the wind-resistant performance of bridges based on larger-scale full bridge aeroelastic models in natural wind. To assess the suitability of wind field for buffeting investigation of long-span bridges based on this novel experimental method, we conducted a 280-day wind field monitoring at the Outdoor Experimental Base for Bridge Wind Engineering (OEBBWE). Results show that the mean wind speed, wind yaw angle, and wind angle of attack are mostly within the ranges of 1–16 m/s, -45–45°, and -3–3°, respectively. The turbulence intensities range mostly from 0.15 to 0.35 for the along-wind direction, 0.1 to 0.30 for the cross-wind direction, and 0.05 to 0.15 for the vertical direction. The turbulence integral length scales are mostly within the ranges of 3–30 m for along-wind and cross-wind direction, 1–5 m for vertical direction. The turbulence power spectral densities (PSDs) also match well with empirical spectra. The results indicate that the natural winds at the site are suitable for buffeting investigations.

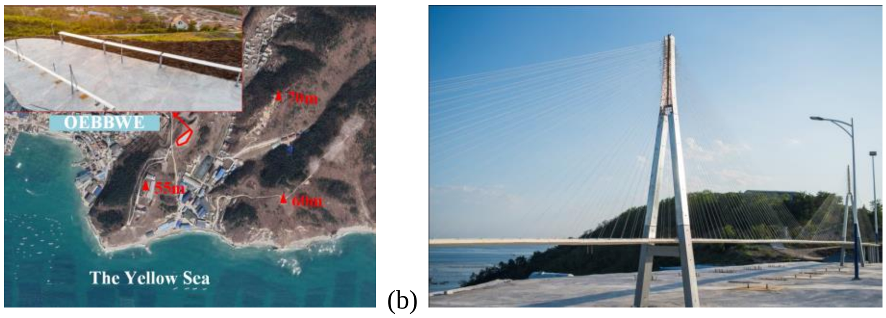
Keywords: natural wind, wind field characteristic, buffeting investigation, full-bridge aeroelastic model

1. INTRODUCTION

Recently, a novel experimental method was presented to study the wind-resistant performances of long-span bridges by using large-scale full-bridge aeroelastic models in natural wind (Ma et al, 2022). This new method overcomes some limitations of both the wind tunnel tests and in-situ measurements and can be used in the buffeting investigation of long-span bridges. The new experimental method has the following advantages compared to conventional wind tunnel testing: (1) the aeroelastic model can be fabricated at a larger geometric scale to reduce the Reynolds number effect; (2) the wind field is closer to the actual situation, and it is convenient to carry out buffeting investigation under different wind field parameters, which occur in natural wind. The new experimental method has the following advantages compared to in-situ measurement: (1) the efficiency of the model utilization can be improved by adjusting the model parameters; (2) remarkable vibration data and cable force are easily measured. While the new experimental method has the above benefits, it is not clear if the wind field is suitable for the buffeting investigation, as the full-bridge aeroelastic model is usually constructed at a height of 1–8 m above the ground, where the wind field is complex and uncontrollable. To address this issue, we conducted a 280-day wind field monitoring at the Outdoor Experimental Base for Bridge Wind Engineering (OEBBWE) of Dalian University of Technology. Based on the measured wind data, the feasibility of utilizing natural wind to study bridge buffeting is analysed in terms of wind speed, wind direction, wind angle of attack, turbulence intensity, turbulence integral length scale, turbulence power spectral density (PSD).

2. OUTDOOR EXPERIMENTAL BASE AND FULL-BRIDGE AEROELASTIC MODEL

The OEBBWE (Fig. 1a) is situated in Dalian, Liaoning Province, on a hill near the sea with an elevation of around 37 m. The base is a northeast-southwest rectangle measuring about 65 m in length and 25 m in width, covering an area of approximately 1600 m^2. There are hills located approximately 220 m southwest, 500 m northeast, and 550 m southeast away from the base, with elevations of 55 m, 70 m, and 60 m, respectively, and some low houses are dispersed among these small hills. As shown in Fig. 1b, an outdoor full-bridge aeroelastic model with a total length of 41.76 m and a height of 6.0 m was built to investigate the wind-resistant performances of a cable-stayed bridge with a scale of 1:50 at the OEBBWE.

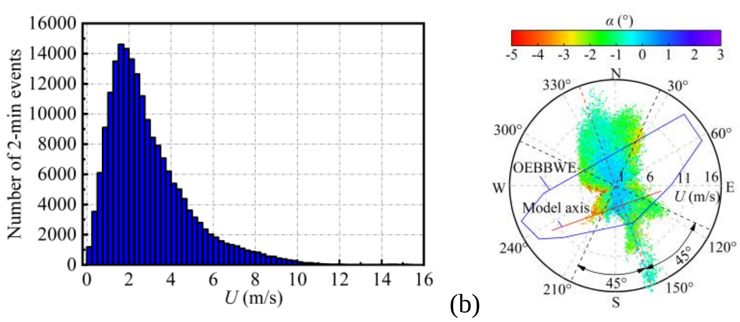


(a) (b)

Figure 1. (a) Location and topography of the OEBBWE and (b) overview of the aeroelastic model

3. MEASUREMENT OF WIND FIELD CHARACTERISTICS

Four Young 81000 anemometers were installed 2 m above the ground to measure the long-term wind speeds at the OEBBWE with a sampling rate of 25 Hz. The wind data were recorded in two periods, from October 6, 2020, to January 6, 2021, and from July 12, 2021, to January 16, 2022, for a total of 280 days. Using a 2 min time interval, a total of 194400 wind speed samples were collected, and the distribution of the mean wind speeds is shown in Fig. 2a as a histogram. It shows that the maximum mean wind speed was approximately 16.8 m/s, and most of the wind speed samples were concentrated in the range of 1–6 m/s. When the mean wind speed is very low, the buffeting response of the bridge model becomes imperceptible. Therefore, we discarded the data with mean wind speeds below 1 m/s, and finally, there were 156080 wind samples in the following analysis.



(a) (b)

Figure 2. (a) Histogram of 2-min samples and (b) wind rose scatter plot of 2-min samples

3.1. Mean wind characteristics

Fig. 2b, displays the wind rose scatter plot with the blue solid line outlining the OEBBWE and the red line representing the central axis of the bridge model. The measured wind records are primarily northwest and southeast winds, and most samples have a yaw angle range of -45°–45°, with some cases perpendicular to the axis of the bridge model. Most samples have a wind angle of attack range of -3°–3°. It is found that the yaw angle and the wind angle of attack are within a range that is realistic for long-span bridges, therefore the mean wind characteristics meet the requirements for buffeting investigation.

3.2. Turbulence intensity

In Fig. 3, the wind rose scatter plots show the turbulence intensities of three fluctuating components. It is seen that the majority of the samples exhibit along-wind turbulence intensities between 0.15 and 0.35, cross-wind turbulence intensities between 0.10 and 0.30, and vertical turbulence intensities between 0.05 and 0.15. The measured turbulence intensity at the OEBBWE is slightly higher than what is commonly encountered for field measurement (Fenerci et al, 2017; Wang et al, 2013), which is mainly due to the following reasons: (1) the small hills surrounding the OEBBWE and the rough surface will increase turbulence intensity; (2) the measuring point is only 2.0 m above the ground, and the incoming flow may be strongly affected by the nearby ground environment. Although the turbulence intensities measured at the OEBBWE are slightly higher, their wide ranges allow us to study the buffeting characteristics of long-span bridges more extensively in different turbulence intensities.

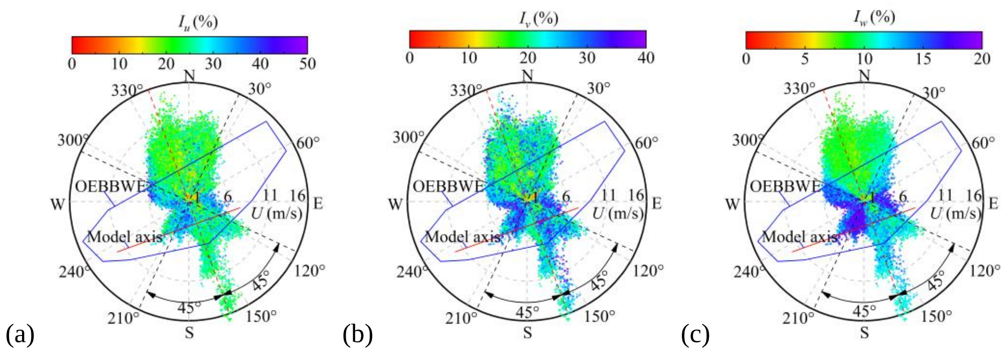


Figure 3. Wind rose scatter plots of turbulence intensities: (a) along-wind turbulence intensity, (b) cross-wind turbulence intensity and (c) vertical turbulence intensity

3.3. Turbulence integral scale

The wind rose scatter plots in Fig. 4 show the turbulence integral length scales of the three fluctuating components. Most samples experience along-wind and cross-wind turbulence length scales between 3 and 30 m and vertical turbulence length scales between 1 and 5 m. Indeed, the measured turbulence length scales are significantly smaller than the values of field measurement (around 100–800 m in the along-wind direction, 100–500 m in the cross-wind direction, and 50–250 m in the vertical direction). This is mainly because the incoming flow near the ground may be strongly affected by the local topography and the ground vegetation to produce small-scale eddies, resulting in an increased turbulence intensity and a reduced turbulence integral length scale. Considering the 1:50 geometric scale ratio of the bridge model, the turbulence integral length scales of the OEBBWE make the wind field suitable for buffeting investigation of the bridge model.

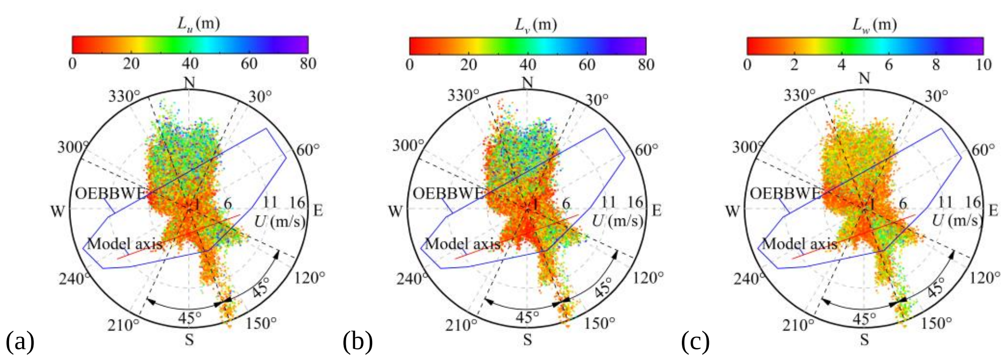


Figure 4. Wind rose scatter plots of turbulence integral scales: (a) along-wind turbulence length scale, (b) cross-wind turbulence length scale and (c) vertical turbulence integral scale

3.4. Turbulence power spectra density (PSD)

We selected a continuous wind speed time series lasting for 7 hours, consisting of 210 samples that cover the period from 4:00 to 11:00 on October 23, 2020, to compute the turbulence PSDs at the site. Fig. 5 displays the turbulence PSDs with error bars, where the error bars represent the standard deviation of the samples, with the Simiu spectrum in red and the Kaimal spectrum in black represented by solid lines. The Welch Method was used to estimate the PSD by dividing the time history of wind speed data into 8 segments with 50% overlap and applying a Hamming window to each segment. It is found that the turbulence PSD measured at the OEBBWE agrees well with the empirical spectrum, indicating that the measured wind field is suitable for buffeting investigation in terms of turbulence PSD.

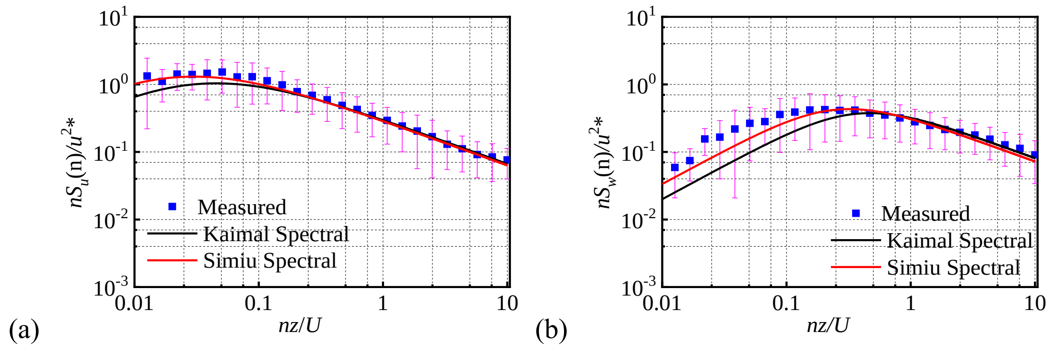


Figure 5. Spectral density estimates of fluctuating components:
(a) along-wind fluctuating component, and (b) vertical fluctuating component

4. CONCLUSIONS

In this study, we conducted a 280-day wind field monitoring at the OEBBWE, and the measured wind field characteristics are summarized as follows: (1) the mean wind speed, the wind yaw angle, and the wind angle of attack at the OEBBWE are within the ranges of 1–16 m/s, -45–45 °, and -3–3 °, and many samples have yaw angles and wind angles of attack close to zero; (2) the majority of the samples show turbulence intensities within the ranges of 0.15–0.35 for the along-wind direction, 0.10–0.30 for the cross-wind direction, and 0.05–0.15 for the vertical direction; (3) considering the 1:50 geometric scale ratio of the bridge model, the turbulence integral length scales at the OEBBWE are found suitable for buffeting investigation, with values around 3-30 m for the along-wind and cross-wind components, and 1–5 m for the vertical component; (4) the measured turbulence PSDs are in good agreement with the empirical spectra. The above findings reveal that the natural winds at the OEBBWE are suitable for buffeting investigations.

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