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Wind-induced risk assessment of large span bridge based on fuzzy analytic hierarchy process

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ABSTRACT:
Management measures for wind-induced risks are very important to ensure the safe operation of large span bridges, and their rationality nature is directly affected by the results of risk assessment. In this paper, fuzzy analytic hierarchy process is used to evaluate the wind-induced risk of a large span bridge in China. Firstly, the uncertainties of wind speed, stress and displacement at the key nodes of the bridge are analyzed based on the field monitoring data of the bridge. The fuzzy evaluation matrix is used to realize the importance ranking and weight optimization of wind induced risk factors, and the risk probabilities are estimated. According to the design parameters of the bridge, the economic loss caused by wind is calculated, and the reasonable evaluation standard is put forward. Finally, the wind-induced risk levels of failure modes are determined and preventive measures are put forward. The research provides a reference for the analysis of wind monitoring parameters on bridges.

Keywords: risk assessment, sea-crossing bridge, wind-induced disaster, fuzzy analytic hierarchy process

1. INSTRUCTION

For a long time, risk has always been an important consideration to ensure the safety of large-scale structures, and it must be predicted and evaluated regularly to propose feasible preventive measures (Stewart *et al*. 2001). For large span bridges in coastal areas, wind-induced response is one of the main risks (Maheux *et al*. 2020, Guo *et al*. 2021, Guo *et al*. 2010). Many researchers assumed that the risk parameters are known and have sufficient data. The increase in sensor capacity and monitoring capability means that more data is available now, so more effective methods are needed to process data (Fujino *et al*. 2019, Guo *et al*. 2022). At present, scholars have done some valuable work in risk assessment of large-scale structures.

Elezaby and El Damatty (2020) evaluated the time-history variation of strain action on various structure elements of a building, and it was concluded that it is necessary to determine the stiffness and strength degradation associated with the occurrence of inelastic cycles during wind events for various structural elements and detailing. Ji *et al*. (2020) believed that probabilistic analysis considering the uncertainties from different sources is necessary for the risk assessment of bridge flutter, they restated modal damping ratio and critical wind speed using generalized flutter analysis, based on which their moments are estimated by adopting point estimate method. Giachetti *et al*. (2021) proposed a quantitative risk analysis method, which is based on the combination of four components (hazard, exposure, vulnerability and damage), and can accurately model according to the analysis objectives. Kim *et al*. (2022) proposed a systematic approach to assess vehicle accident risk over large span bridges in strong winds, the approach considered the effect that deck shapes and road alignments exert on vehicle stability.

As the large span bridge is a large-scale building with complex structure, the key parts will have different risks to the overall structure under the wind load. It is necessary to compare the importance of risk factors for assessment, which will help to formulate more reasonable management measures. As a systematic analysis method combining qualitative and quantitative analysis, fuzzy analytic hierarchy process solves the problems existing in traditional analysis methods and improves the reliability of decision making (Kabir *et al*. 2014, Bouzon *et al*. 2016). Through the calculation of comprehensive importance, all situations are ranked to provide scientific decision-making basis. The method is applied to the wind-induced risk assessment of large span bridges, which provides a reference for the analysis of monitoring parameters and has certain theoretical value and practical significance. The monitoring situation and wind load parameters of the bridge to be studied are respectively introduced below.

2. PROJECT OVERVIEW OF XIHOUMEN BRIDGE

Xihoumen Bridge is the main part of an island linking project, with a total length of 5452 m and a cost of 370 million dollars, as shown in Fig. 1. The main design of the bridge is a three-span suspension bridge with a span of 578 m+1,650 m+485 m. The main cable is a two-span continuous suspension cable. The bridge has four lanes, with a vertical navigation height of 49.5 m and a tower height of 236.486 m, as shown in Fig. 2. According to various physical wind tunnel tests and computational fluid dynamics calculations, Xihoumen Bridge adopts a streamlined double box girder with a total width of 36 m. The whole stiffening beam is 2228 m long, and the middle of the stiffening beam is slotted 6 m. Each box girder is made of orthotropic plates with a width of 15 m and reinforced by beams with a longitudinal spacing of 3.6 m. The two independent box girders are connected by two types of beams, that is, the beam has a box section at the suspender and an I-section in the middle of the two booms.


Figure 1. Aerial view of Xihoumen Bridge

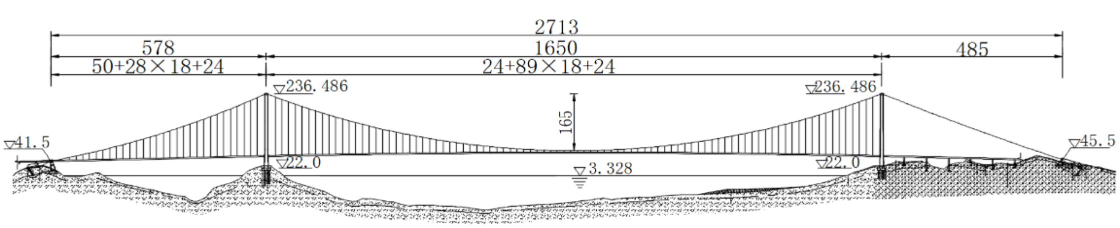


Figure 2. Overall layout of the Xihoumen Bridge (m)

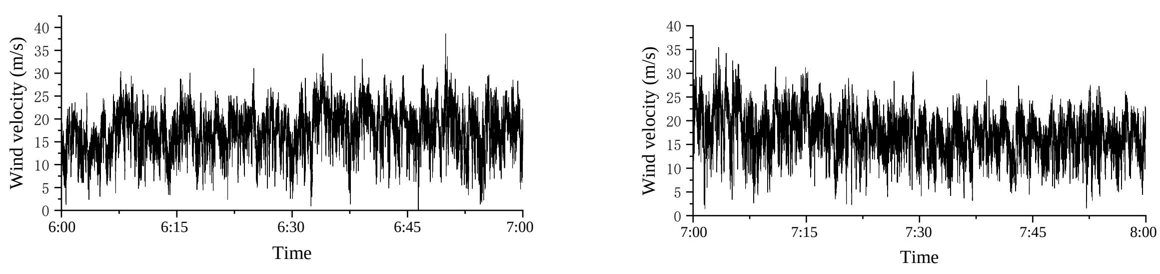
Xihoumen Bridge was formally opened to traffic on December 25, 2009. In order to ensure the normal operation of the bridge, a complete structural health monitoring system was established to monitor the operation stage of the bridge. The monitoring contents of the system can be summarized into load source monitoring and structural response monitoring. Load source monitoring includes monitoring of wind load, temperature, humidity and earthquake, and structural response monitoring includes monitoring of spatial displacement and steel box girder stress, etc. The sensor parameters are shown in Table 1.

Table 1. Sensor parameters

Sensor	Position	Sampling frequency	Quantity
Propeller anemometer	tower top	1 Hz	2
Three-way ultrasonic anemometer	1/4, 1/2 and 3/4 of the main beam	32 Hz	6
Uniaxial acceleration sensor	1/4, 1/2 and 3/4 of the main beam, Side span 1/2 place, tower bottom	30 Hz	30

3. WIND LOAD PARAMETERS

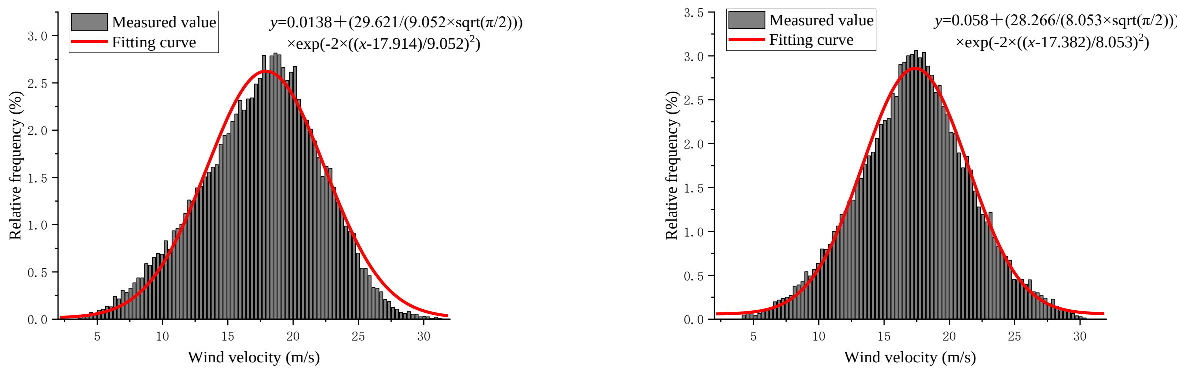
The historical meteorological data collected since 1956 show that the bridge site is affected by seasonal wind from November to March of the following year, with the average wind speed of 14~20 m/s, class 7~9. Comparing the strong wind records obtained by the long-term monitoring system of the bridge, the most representative two hours of wind speed during the Severe Typhoon In-Fa (6:00-8:00 July 25, 2021 UTC+8) were selected to analyze the distribution of instantaneous wind speed. The wind speed along the bridge direction and across the bridge direction measured by the ultrasonic anemometer at the mid-span position is taken, and the actual wind speed is obtained after vector superposition. as shown in Fig. 3. The maximum instantaneous wind speed in the previous hour is 38.63 m/s, and the maximum 10-min average wind speed is 18.73 m/s. The maximum instantaneous wind speed in the later hour is 35.45 m/s, and the maximum 10-min average wind speed is 18.9 m/s, which is also the maximum average wind speed in the whole typhoon period.



(a) 6:00-7:00 (UTC+8) (b) 7:00-8:00 (UTC+8)

Figure 3. Time series of wind speed at the bridge site under the Severe Typhoon In-Fa (July 25, 2021)

The Pauta criterion is used to eliminate outliers from the data, that is, to eliminate the points in the sample whose absolute value is more than three times the standard deviation. The Gaussian function is used to fit the wind speed data, as shown in Fig. 4. Through comparison, it is found that in the expression of fitting function, the change of each parameter can clearly reflect the distribution of instantaneous wind speed in different time intervals. Thus, the Gaussian function has a good fitting effect on the wind speed probability model of typhoon.



(a) 6:00-7:00 (UTC+8) (b) 7:00-8:00 (UTC+8)

Figure 4. Relative frequency of typhoon measured data and its fitting curve

Fuzzy analytic hierarchy process is used to evaluate the wind-induced risk of a large span bridge in China, and the specific research content will be carried out later.

4. ACKNOWLEDGMENTS

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