August 27-31, 2023
FLORENCE - ITALY
ICWE 16
16th International Conference on Wind Engineering

Aerodynamic stability of super-long-span L-shaped wind fairing steel box girder suspension bridge

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SUMMARY:
At present, the span of suspension bridges that have been built or under construction has exceeded 2000 m, and the planned span has exceeded 3000 m. In order to meet the increasing traffic demand, more super-long-span suspension bridges will be built in the future. In this paper, the aerodynamic stability of steel box girder suspension bridge with super long span L-shaped wind fairing is studied by wind tunnel test and CFD. Firstly, based on this section, six suspension bridges with spans from 1098 m to 3000 m are designed, and the aerodynamic shape is optimized by wind tunnel test. Then, the numerical simulation of this type of section and streamline section is carried out, and the flow field characteristics are compared and analyzed. The results show that the torsional frequency and aerodynamic shape are the main factors affecting the critical wind speed of flutter. The steel box girder section with L-shaped wind fairing has better aerodynamic stability than the streamlined steel box girder section. The advantage is that the section will separate the incoming flow in the upstream of the section, and the generated turbulence fills the negative pressure area and reduces the formation of large-scale vortices.

Keywords: wind tunnel test, CFD, aerodynamic stability

1. GENERAL INSTRUCTIONS

The largest span of suspension bridges in the world is the 1915 Canakkale Bridge with a main span of 2023m. The largest span under construction is the Zhangjinggao Yangtze River Bridge with a main span of 2300m. The planned Messina Strait Bridge has a main span of 3300m. The suspension bridge is developing towards a super large span. There are many domestic islands in Italy, Norway, Denmark and Southeast Asia, and the Yangtze River and Pearl River basins in China are wide. In the face of increasing traffic volume, the demand for super-span suspension bridges is only increasing. The flutter critical wind speed of the existing steel box girder section needs to be improved. With the increase of span, the structural stiffness decreases, and the wind-induced vibration is more likely to occur. Therefore, one of the serious problems faced by the super long-span suspension bridge is the super high flutter critical wind speed and good aerodynamic stability.

In the wind resistance test of a suspension bridge with a main span of 1098 m, the bridge has good vortex vibration performance and ultra-high flutter critical wind speed. The main girder is a steel box girder with L-shaped wind fairing, and the aerodynamic stability of the main girder is good. Therefore, based on this kind of section, this paper designs other five span suspension bridges, of which the maximum main span is 3000 m. By optimizing the aerodynamic shape, a higher flutter critical wind speed is achieved. At the same time, the flow field characteristics of such section and streamlined steel box girder section are compared and analyzed by numerical simulation.

2. METHODOLOGY

The main girders are straight web steel box girders with inverted L-shaped wind fairing. The sections are shown in Figure 1, and the dynamic characteristics of each span are shown in Table 1. Considering the requirements of section size, model quality and blocking rate of wind tunnel test section, the scale ratio of two types of section model is selected as 1:60. The test was carried out in the CA-03 wind tunnel laboratory of Chang 'an University, as shown in Figure 2.

Table 1. Summary of dynamic characteristics.

L (m)	D (m)	fh (Hz)	ft (Hz)	m (kg/m)	Im (kg*m^2/m)
1098	3.2	0.098	0.358	5.06E+04	4.29E+06
1666	3.2	0.079	0.210	6.54E+04	1.08E+07
2300	3.2	0.068	0.146	6.81E+04	1.42E+07
2500	4	0.065	0.132	7.01E+04	1.55E+07
2800	4	0.062	0.116	7.42E+04	1.77E+07
3000	4	0.060	0.107	7.74E+04	1.94E+07

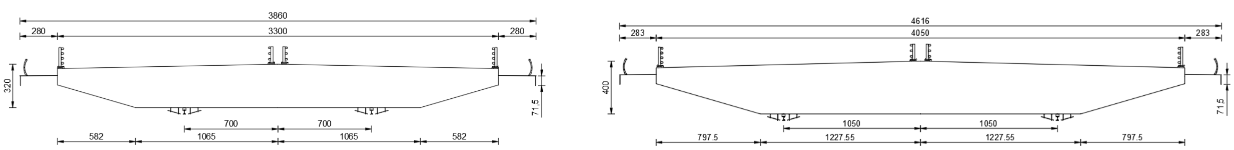


Figure 1. Standard section of main girder (unit: cm).

The construction sections of three types of steel box girders shown in Figure 3 are selected for comparative analysis of aerodynamic characteristics and flutter stability. The computational domain is set as shown in the figure 4. The unstructured grid is used, the k-ω SST turbulence model is used, and the SIMPLEC algorithm is used for calculation. The bridge section is non-slip wall condition; the inlet boundary is the velocity inlet, and the turbulence intensity and turbulence viscosity ratio are 0.5 % and 10 % respectively. The outlet boundary pressure is 0 ; the upper and lower sides are symmetrical boundary conditions. After grid independence verification, comprehensive consideration 314,000 cross-sections, 327,000 cross-sections, and 309,000 cross-sections are selected as the final calculation grids. As shown in Figure 5, the near-wall mesh Yplus of the three bridge sections is less than 1.

Figure 2. Segmental model diagram.

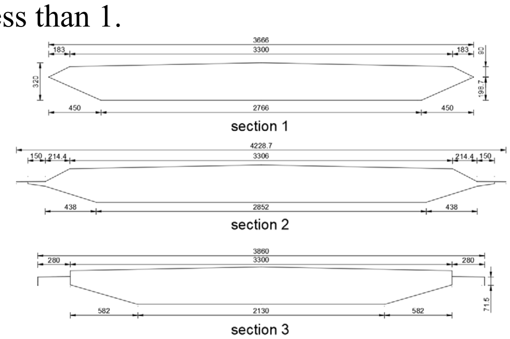


Figure 3. Three types of section.

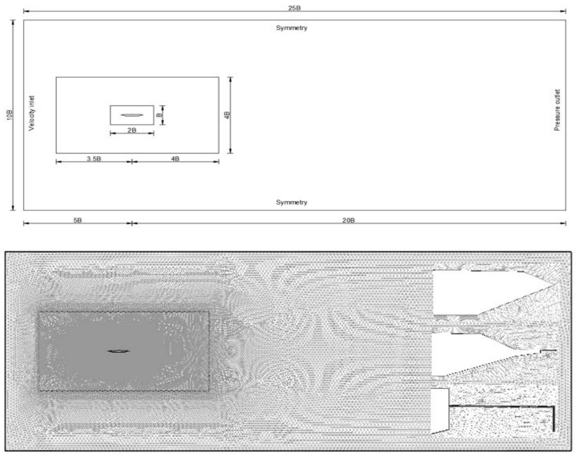


Figure 4. Boundary condition of calculation area and mesh.

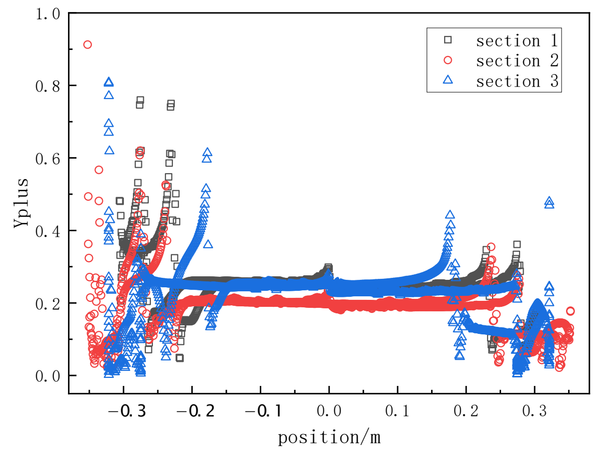
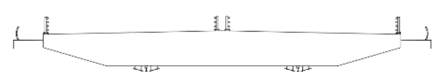
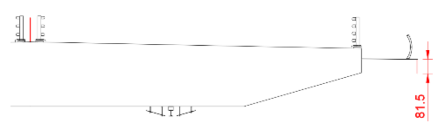
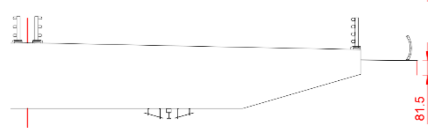
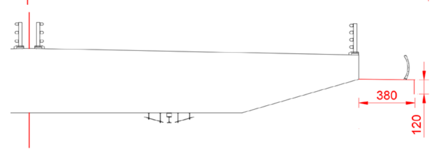
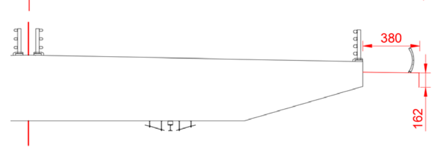


Figure 5. Wall y+ value.

3. RESULT AND DISCUSSION

In the wind tunnel test, the parameters are continuously optimized to obtain the optimal aerodynamic shape. The flutter critical wind speed of each span is shown in table 2. 2500 'and 2800' in the table represent the test results of only changing the original torsional frequency to 0.15 and 0.14. This kind of section has good aerodynamic performance, and still has high flutter critical wind speed in the case of large span. When the span is the same, the flutter critical wind speed is higher than that of other types of sections(Huang, 2022; Zhao, 2019).

Table 2. Flutter stability test results.

L(m)	flutter speed(m/s)	aerodynamic measures	diagram
1098	>142.6	2.8m×0.715m inverted L plate	
1666	106.96	2.8m×0.815m inverted L plate + 1.2m upper central stabilizer	
2300	80.64	2.8m×0.815m inverted L plate + 1.2m upper central stabilizer + 0.915m lower central stabilizer plate	
2500	68.4	3.8 m×1.2m L plate + 1.8m upper central stabilizer + 1.74 m lower central stabilizer	
2500’	80.19	3.8m×1.62m L plate + 1.6m upper central stabilizing plate + 1.2m lower central stabilizing plate	

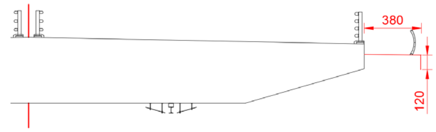
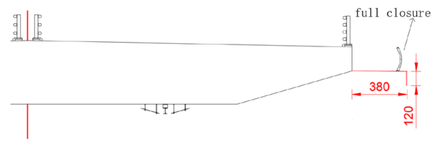
2800’	78.02	3.8m×1.62m L plate + 1.2m upper central stabilizing plate + 1.2m lower central stabilizing plate	
3000	60.5	1.5m upper central stability plate + 3.8m×1.2m L plate moved to the bottom + 1.74m lower central stability plate + closed maintenance road guardrail	

Figure 6 shows the velocity distribution of three types of sections. It can be seen from the diagram that section 3 produces vortexes at both ends of the main girder, while section 1 and section 2 only produce vortexes at the trailing edge. The existence of the L plate makes the incoming flow begin to separate through the upstream of the section, and the generated turbulence fills the negative pressure area, which reduces the generation of large-scale vortices.

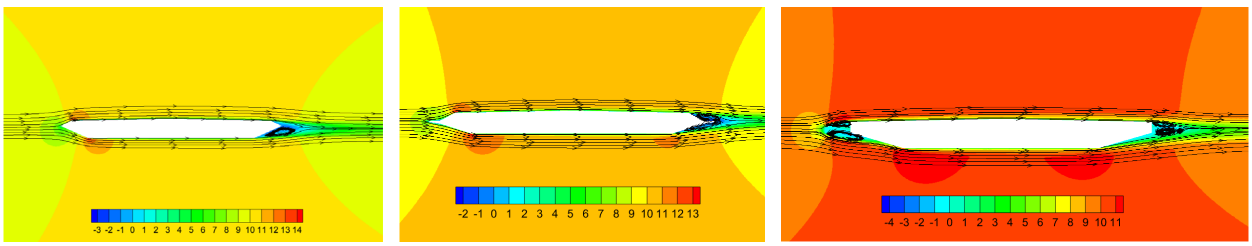


Figure 6. Velocity contours of girders.

4. CONCLUSION

Torsional frequency and aerodynamic shape are two main factors affecting the critical wind speed of bridge flutter.

With the increase of span, the torsional frequency of steel box girder suspension bridge decreases rapidly, and the spatial cable can be used to improve the torsional frequency.

The steel box girder section of the L-shaped wind fairing has better aerodynamic stability than the streamlined steel box girder section. Its superiority is that the section will separate the incoming flow in the upstream of the section, and the generated turbulence fills the negative pressure zone and reduces the formation of large-scale vortices.

For super-long-span suspension bridges, in order to achieve higher flutter critical wind speed, it is recommended to use steel box girders with space cables and L-shaped wind fairing.

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