(a) Scheme 2

(b) Scheme 3

Fig.5 Bridge Girder Schemes

3.2.1 model and parameters

The scaling factor of the rigid model is 1:40. The model is made of light synthetic materials. The test device is an inner bracket. In order to ensure the 2-D characteristic, we set up a binary end plate on both sides of the model. The sectional model hanging in wind tunnel is shown in Fig.6. The parameters of Scheme 2 and Scheme 3 are in Table 3.

Fig.6 Vibration model test

Table.3 Design Parameters of the Sectional Model

scheme	parameters	Practical value	Similar relation	Model design value	Measured value	Relative error (%)
Scheme 2	Bending frequency/ Hz	0.0724	75/3.6	1.51	1.47	2.65
	Torsional frequency/ Hz	0.2075	75/3.6	4.32	4.35	0.69

Scheme 3	Bending frequency/ Hz	0.0724	75/3.6	1.51	1.48	2.0
	Torsional frequency/ Hz	0.2121	75/3.6	4.42	4.57	3.4

3.2.2 test results and analysis

Table.4 three-component coefficients and Parameters of F of the Closed Steel Box Beam at Three Wind Attack Angle

scheme	C_D	C_L	C_M	C_L'	C_M'	$\lvert C_L' C_M' \rvert$	F
Scheme 2	1.270	0.096	0.039	3.669	0.831	3.050	-1.077
Scheme 3	0.948	0.050	0.051	2.494	0.860	2.144	-0.584

Table.5 Flutter Critical Wind Speed and Parameters of F of the Closed Steel Box Beam at Three Wind Attack Angle

scheme	F	flutter critical wind speed(m/s)
Scheme 2	-1.077	46.8
Scheme 3	-0.584	70.2

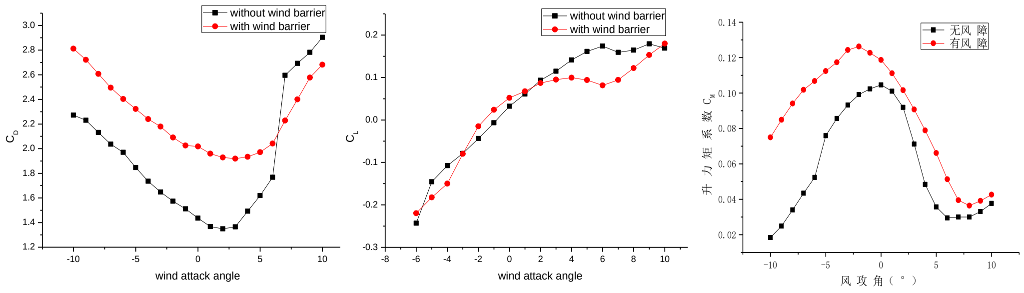
Table 4 shows three-component coefficients and F of Scheme 2 and Scheme 3. Table 5 shows the results of F and flutter critical wind speed of the two schemes. From the above table, we can see that F of Scheme 2 is smaller than Scheme 3 and the flutter critical wind speed of Scheme 2 is smaller than Scheme 3, too. For closed steel box beam, the greater the value of the F parameter, the flutter stability is better.

3.3 Test results of the Slotted Steel Box Beam

The Preliminary design scheme of HZMB Jianghai direct ship channel bridge is a three-tower cable-stayed bridge with a 258-meter main span. The main girder is the slotted box beam, shown in Fig.7.

Fig.7 Bridge Girder Schemes

The wind tunnel test is consist of wind barrier scheme and without wind barrier scheme. Fig.8 shows the results of the two schemes.



(a) C_D (b) C_L (c) C_M

Fig.8 Three-Component Coefficients of Different Schemes

Table.6 Three-Component Coefficients and Parameters of F of the Slotted Steel Box Beam at Zero Wind Attack Angle

scheme	C_D	C_L	C_M	C_L'	C_M'	$\left\|C_L'C_M'\right\|$	F
With wind barrier	2.018	0.052	0.119	1.755	-0.311	0.546	-0.358
Without wind barrier	1.436	0.032	0.105	1.784	-0.227	0.405	0.894

Table.7 Flutter Critical Wind Speed and Parameters of F of the Slotted Steel Box Beam at Zero Wind Attack Angle

scheme	F	flutter critical wind speed(m/s)
Scheme 2	-0.3575	100.65
Scheme 3	0.8939	116

Table 6 shows Three-Component Coefficients and Parameters of F of the two schemes. Table 7 shows F and flutter critical wind speed. We can see that for the slotted steel box beam, the greater the value of the F parameter, the flutter stability is better.

4. NUMERICAL SIMULATION

This section uses FLUENT to make the numerical simulation analysis of streamline deck based on the deck of Qipanzhou Bridge. In order to prove the parameters of F, we use three beams of equal width and different width to calculate their three-component coefficients and critical flutter speed under 0° wind attack angle.

4.1 Model and Parameters

The simulation uses k-ω turbulence model which is better in simulating external disturbance flow. The equation is solved by using SIMPILEC algorithm. The scaling factor of the model is 1:60. Fig.9 shows Scheme 1(original scheme). The boundary condition of the model is shown in Fig.10. The parameters of Scheme 1 to Scheme 3 are shown in Table 8.

Fig.9 Girder of Scheme 1

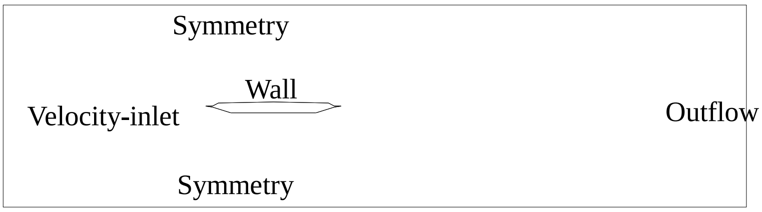


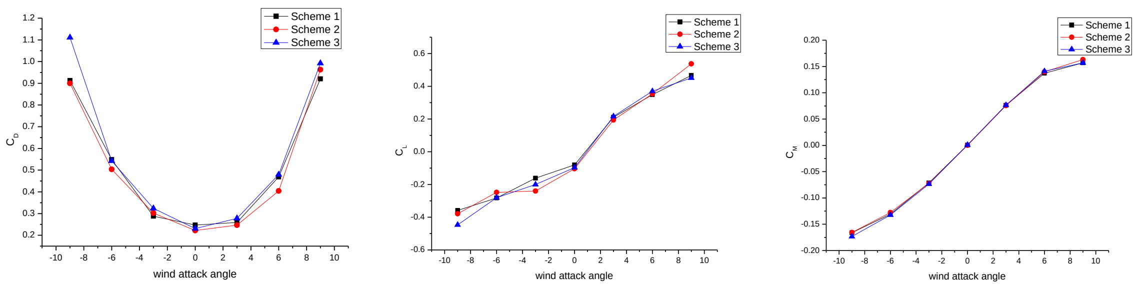
Fig.10 Boundary Condition of the Model

Table.8 Parameters of Scheme 1 to Scheme 3

	Size	Scheme 1	Scheme 2	Scheme 3
Actual bridge	Beam depth /m	3.00	3.00	3.00
	Beam width /m	38.50	35.50	41.50
Model	Beam depth /m	0.05	0.05	0.05
	Beam width /m	0.64	0.59	0.69

4.2 Results of the Numerical Simulation Analysis

Fig.11 shows three-component coefficients of the three schemes.



(a) C_D (b) C_L (c) C_M

Fig.11 Three-Component Coefficients of Different Schemes

Table. 9 Three-Component Coefficients and Parameters of F

scheme	C_D	C_L	C_M	C_L'	C_M'	$\lvert C_L' C_M' \rvert$	F
Scheme 1	0.247	-0.081	0.001	3.788	1.451	5.497	0.0146
Scheme 2	0.222	-0.104	0.000	4.795	1.455	6.978	0.0249
Scheme 3	0.231	-0.097	0.001	4.382	1.470	6.439	0.0205

Table.10 Flutter Critical Wind Speed and Parameters of F

scheme	F	flutter critical wind speed(m/s)
Scheme 1	0.0146	154.76
Scheme 2	0.0249	171.96
Scheme 3	0.0205	161.17

Table 9 shows Three-Component Coefficients and Parameters of F of the three schemes. Table 10 shows F and flutter critical wind speed. The simulation shows that for the streamline beam, the greater the value of the F parameter, the flutter stability is better.

5.CONCLUTION

(1) This paper determines the relationship between three-component coefficients and flutter derivatives based on frequency domain analysis and analyzes the aerodynamic damping matrix, aerodynamic stiffness matrix and the driving mechanism of bending-torsional coupling. Thus, we can do research on flutter stability by three-component coefficients instead of flutter derivatives.

(2) The rapid evaluation parameter,F, is put forward. When C_L ' C_D ' C_M are positive, the smaller it's value is, the better. If C_L ' C_D ' C_M are negative, the smaller it's absolute value is, the better. The bigger $\lvert C_L' C_M' \rvert$ is, the more likely the bridge structure will occur flutter instability.

(3) This paper introduces the typical bridge sections of long span suspension bridge, including truss section, closed steel box girder and slotted steel box girder. Then evaluate the effectiveness of F parameter based on the results of the wind tunnel test.

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