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Wind tunnel test research on aerodynamic means of the ZG Bridge

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Abstract. The ZG Bridge(preliminary design), with unfavorable aerodynamic stability characteristics, is a truss-stiffened suspension bridge, its critical wind speed of flutter instability is much lower than that of code requirement, In the present paper, based on both aerostatic and aeroelastic section model wind tunnel tests, not only effects of some aerodynamic means on aerodynamic stability of its main girder are investigated, but also such effective aerodynamic means of it as flap and plate-like center stabilizer are concluded.

key words: flutter; wind tunnel test; flap; plate-like center stabilizer.

1. Introduction

The ZG Bridge(preliminary design) is a highway suspension bridge with a steel truss stiffening girder, the span construction of which is as shown in Fig. 1. Its tower is 50.0 m high, and the cross section of the stiffening steel truss is 8.5 m wide and 3.0 m deep respectively.

For reference, the primary dimensions of the ZG Bridge are shown in Table 1.

Generally speaking, a stiffening truss can be designed to exhibit sufficient torsion stiffness to safeguard a suspension bridge against torsion flutter instability by introducing horizontal top and bottom wind bracing and adopting a depth of 1/170~1/120 of the span length (Ostenfeld and Larsen 1992), but in the case of the ZG Bridge, the depth of its stiffening truss is only approximately 1/228 times of its span length. On the other hand, owing to the dead load of its stiffening truss being 18.8 kN/m only, the gravity stiffness of cable is rather insufficient. These probably make its onset of flutter easier. In fact, during the aeroelastic section model wind tunnel testing, it was found out that when the deck being slotted and the angle of attack of wind - α

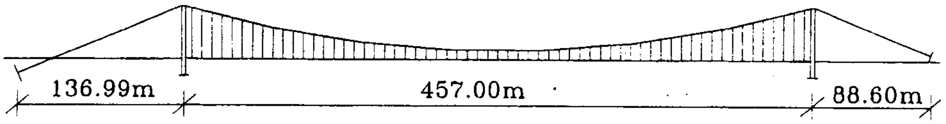

Fig. 1 General view of the ZG Bridge

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Table 1 Primary dimensions of the ZG Bridge

Main span(m)		457.00
Stiffening girder(m)		8.5×3.0
Dead load(kN/m)	Stiffening girder	18.8
Natural frequency(Hz)	1st lateral bending	0.1243
	1st vertical bending	0.3019
	lst tortion	0.6905
Reference wind speed at stiffening girder(m/s)		40.0
Flutter-proof wind speed(m/s)		48.0

being +3°, its critical wind speed of flutter is only 28.0 m/s, which is much less than its flutter-proof wind speed- $[U_{cr}]$ (for the ZG Bridge : $[U_{cr}] = 48.0$ m/s, Zhang 1997).

Although the structural configuration shall be firstly determined in accordance with structural and functional requirements, consideration on aerodynamic stability at preliminary design stage is very essential for long-span suspension bridges located at the site where strong wind is anticipated. As retrofits of preliminary design, such kinds of aerodynamic means as flap, wind-plate and plate-like center stabilizer and so on· should be very effective to improve the aerodynamic stability of stiffening trusses, so the researches based on section model wind tunnel tests should be of great importance.

2. Aerostatic section model tests

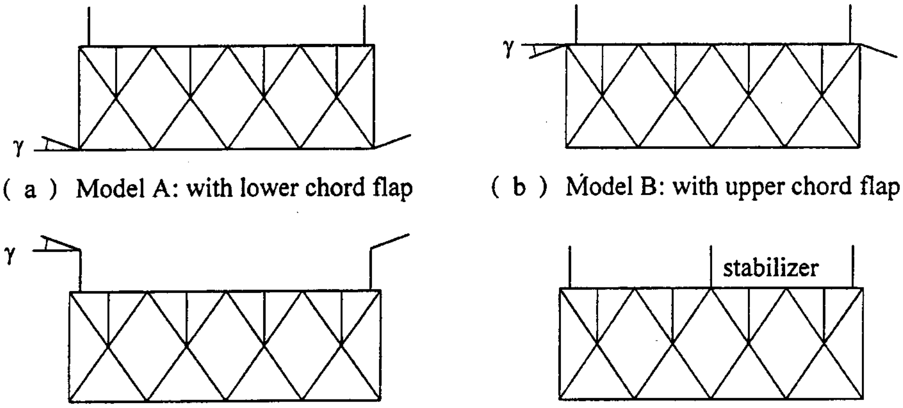
One of the basic goal of aerostatic section model wind test is to measure stationary wind load coefficient for the candidated girder configuration. In terms of aerostatic theory, the stationary wind drag (P_H), lift (P_V) and torsional moment (M) can be discribed as Eq. (1) (under body coordinate) :

$$P_H = \frac{1}{2}\rho U^2 C_D D$$
$$P_V = \frac{1}{2}\rho U^2 C_L B$$
$$M = \frac{1}{2}\rho U^2 C_M B^2 \tag{1}$$

where : ρ is the density of air; U is the wind speed; D and B are the depth and width of the girder respectively; C_D, C_L and C_M are coefficients of stationary wind drag, lift and torsional moment individually.

A series of experiment were carried out in the industrial wind tunnel (XNJD-1) of Southwest Jiaotong University, which has a test section with dimensions of 2.0 m height × 2.4 m width × 16.0 m length.

The length scale for section model of the ZG Bridge was $\lambda_L = D_m / D_p = 1/13$, where the subscripts "$m$" and "$p$" referred respectively to model and prototype. Besides the model with original cross section of stiffening truss, the models with following aerodynamic attachments were used for the present research, which were all truncated at nodes of chord for the purpose of being restricted by practical considerations such as details of connection of the attachments



(a) Model A: with lower chord flap (b) Model B: with upper chord flap

(c) Model C: with wing-plate on rails (d) Model D: with center stabilizer

Fig. 2 Sketch of modified model cross sections

with girders and economic, etc.

2.1. Flap-fixed on lower or upper chord

A pair of flap, which was 123 mm wide and 3 mm thick, were fixed on lower or upper chord with a changing slope angle (γ) respectively. γ was arranged to be 0°, +3°, +5°, +8°, +10°, +20°, +25°, +30°, +40° respectively for lower chord flap and -10°, -5°, -3°, 0°, +5°, +10° for upper chord flap. γ was positive when the flap was swung up toward, otherwise it was negative. The modified model cross section, which was identified as "Model A" and "Model B" respectively, are illustrated in Fig. 2a and Fig. 2b for each.

Comparing the results of Model A and that of original model, it is found out that : when α (angle of attack of wind) being 0° and γ changing from 0° to +10°, the C_L of Model A becomes negative from positive, which should be helpful to compensate the insufficientment of cable gravity stiffness of the ZG Bridge, but the fluctuation of C_D is not obvious; when γ change from +10° to +40°, the C_D roses obviously so that it is greater than that of original model rapidly. It may be inferred from the phenomenon described above that the low chord flap should improve aerodynamic stability of the stiffening truss effectively when γ designed between 0° and +10° for $\alpha = 0°$ or $\alpha = +3°$ (Zhang 1997).

The influence of γ of upper chord flap on coefficients of stationary wind forced when α being 0° or +3° are illustrated in Fig. 3a and Fig. 3b individually.

In Fig. 3, when α being 0° or +3° and γ changing from -10° to +10°, the changing of C_D and C_L of Model B are very little, and the C_M is negative when γ is less than -5° (for $\alpha = 0°$) or equal to -10° (for $\alpha = +3°$) respectively. It seems as if the negative C_M is helpful to raise critical wind speed of flutter under 0° or positive angle of attack of wind (He 1998).

2.2. Wing-plate

A pair of wing-plate, which was 38.46 mm wide and 3mm thick, were fixed on the top of rails with a changing slope angle (γ). γ was arranged to be 0° , +3° , +5° , +10° , +20° , +30°

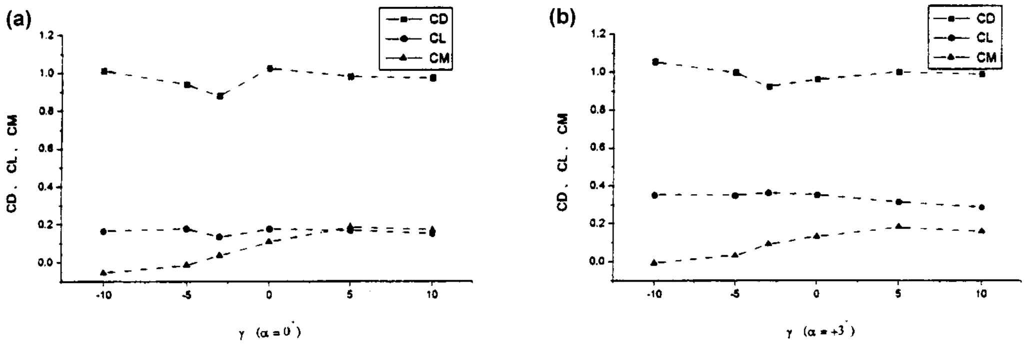


Fig. 3 The influence of γ of upper chord flap on coefficients of stationary wind forces

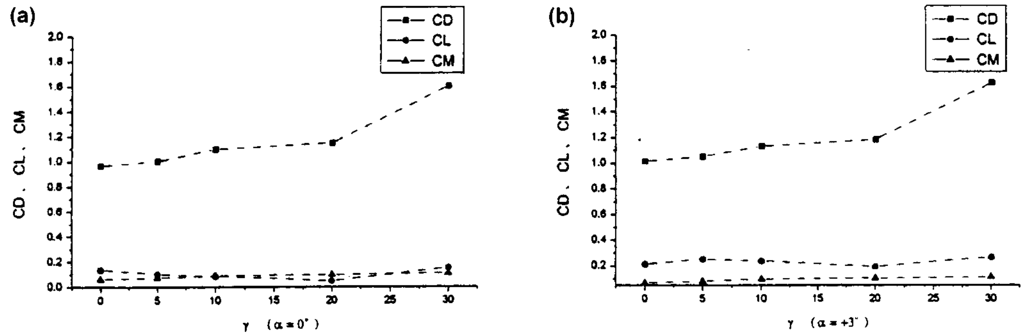


Fig. 4 The influence of γ of wing-plate on coefficients of stationary wind forces

respectively. The modified model cross section, which is identified as "Model C" is illustrated in Fig. 2c.

The influence of γ of wind-plate on coefficients of stationary wind forces when α being 0° or $+3^\circ$ are illustrated in Fig. 4a and Fig. 4b individually.

In Fig. 4a, when α being 0° and γ being less than $+20^\circ$, the changing of positive C_D, C_L and C_M are rather slow, but the positive C_D and C_L rise quickly after γ being greater than $+20^\circ$. In Fig. 4b, when α being $+3^\circ$, the C_D and C_L are almost unchanged, and C_D is only changed slightly when γ is less than $+20^\circ$, but as soon as γ is greater than $+20^\circ$, the C_D rises speedily, which means that it is likely impossible for the wing-plate to improve the aerodynamic stability, as being proved by experiments later (He 1998).

2.3. Plate-like center stabilizer

In the case of truss-stiffened suspension bridge, openings on the roadway such as gratings and/or separation between the upper chord of main truss and the road deck are usually provided from the point view of aerodynamic stability, however, it should be taken into account in this case that the onset of flutter is quite susceptible to such minor modification as the change of the depth of curb stone and the position of additive components like inspection gallery, rails and power lines and so on installed inside or on the suspended truss structure

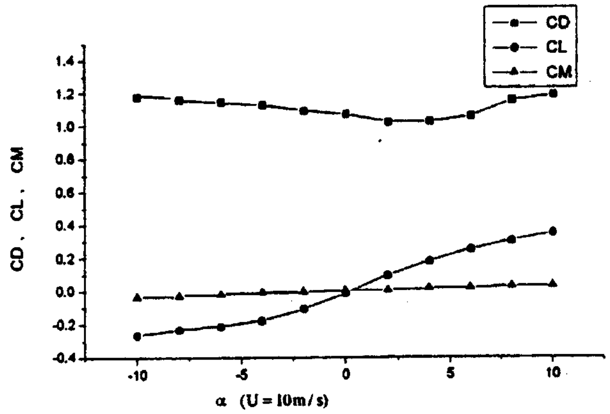


Fig. 5 Coefficients of stationary wind forces for Model D

(Ito 1992).

A plate-like center stabilizer, which was 38.46 mm high and 3 mm thick, was fixed at center of deck. The modified model across section, which is identified as "Model D" is illustrated in Fig. 2d.

Fig. 5 indicates the relationship between angle of attack of wind and the coefficients of stationary wind forces for Model *D*, specifically, C_M and C_L has come to be very little when α changing between 0° and +3°.

For the Akashi Kaikyo Bridge, a truss stiffened long-span suspension in Japan, it was also found out that although a pair of triangle fair fixed on two side of the girder raised the critical wind speed of flutter remarkably, however, a large torsional vortex induced excitation was to take place. On the contrary, by adopting a kind of plate-like stabilizer, together with a closed fence at the center of the road deck, the needs of both aerodynamic and suppression of vortex induced vibration were satisfied at the same time (Miyata and Yanuguchi 1993).

3. Aeroelastic section model tests

As for suspension bridges, aeroelastic section model test is the most common method used to predict its critical wind speed of flutter, because its results are usually credible and secure.

The critical wind speed of flutter were measured by aeroelastic section model wind tunnel tests for Model A-D and some of the results are illustrated in Fig. 6, Fig. 7 and Fig. 8 respectively. Because the criteria wind speed of flutter of original model under α= -3° was higher than those under α= 0° or α = +3°, the aeroelastic section model tests were all achieved under α= 0° and α= +3°. In addition, as no severe vortex induced vibrations had occurred, only critical wind speeds of flutter of Model A-D were measured.

In Fig. 6, when α being 0° or +3° and γ changing between 0° and +10°, the critical wind speed of flutter of Model A rises obviously, for example, when α being +3° and γ being +5°, the critical speed rises from 30 m/s of original model to 80 m/s (referring to speed of prototype).

In Fig. 7, when α being 0° or +3° and γ changing between -10° and -3°, the critical speed of Model B are all higher than those of original model, and the highest one is 80 m/s when γ is -5° (for +3° angle of attack of wind), while the critical speed of original model were only

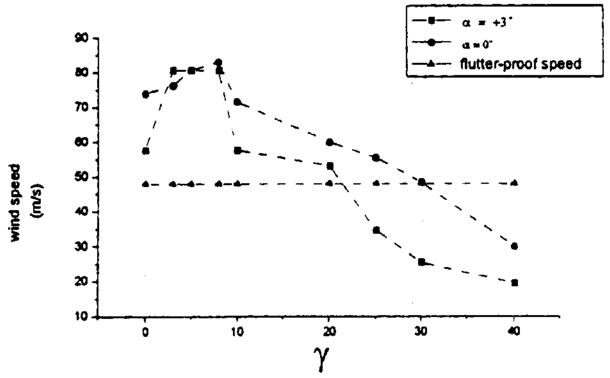


Fig. 6 Influence of γ of lower chord flap on the critical wind speed of flutter

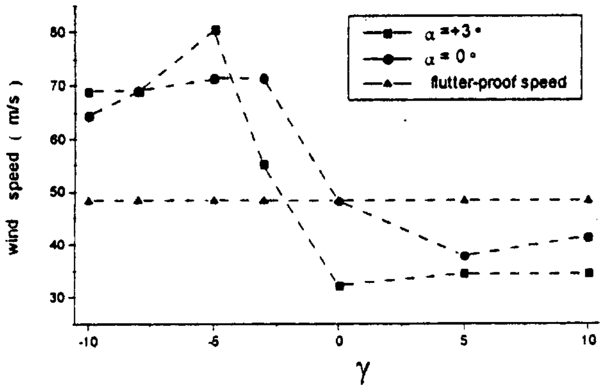


Fig. 7 Influence of γ of upper chord flap on the critical wind speed of flutter

about 30 m/s under the same angle of attack of wind. So upper chord flap should be an effective aerodynamic attachments for the ZG Bridge.

In Fig. 8, when α being 0° and γ being 0°, +5°, +10°, +20° and +30° respectively, the critical

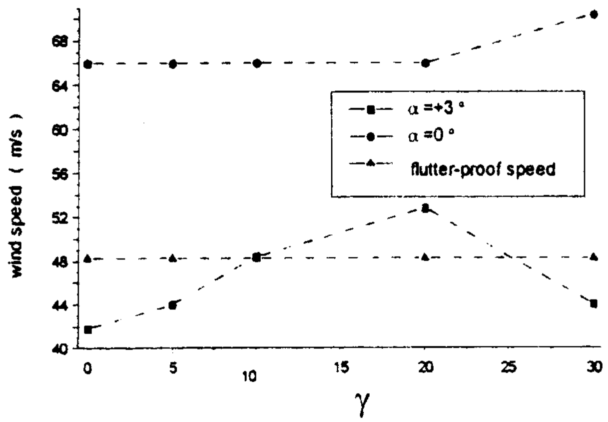


Fig. 8 Influence of γ of wing-plate on the critical wind speed of flutter

speed can be raised to a satisfying standard, but when α being +3°, it is higher than its flutter-proof speed (48 m/s) only when γ is +20°. So it should be impossible for the wing-plate to improve the aerodynamic stability of the ZG Bridge effectively.

It is found out from the test results of Model D that when α being 0° or +3°, its critical wind speeds are all higher than 65 m/s. Because of its convenience and effects, the plate-like center stabilizer should be one of the most effective and economical aerodynamic means for the ZG Bridge.

4. Conclusions

The results of study are summarized as follows :

1) Aerodynamic means should play an important role in the evolution of the design of modern large bridges.
2) As to large-span suspension bridges, better aerodynamic performance of main girder could be achieved by the use of suitable aerodynamic means.
3) The wind tunnel is an indispensable tool for research on the aerodynamic means of bridges. Moreover, the effects of the aerodynamic means on vortex induced vibration and buffeting should be investigated further by wind tunnel test.

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