

Experimental study on vortex resonance of streamline-like bridge deck section

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ABSTRACT: In order to study the vortex-induced vibration and characteristics of high-order torsion vortex-induced vibration in streamline-like bridge deck section, model with pressure taps supported by spring was made for wind tunnel test, which included the torsion amplitude and time-history wind pressure in each tap. Based on the analyses of vibration spectrum in two vortex vibration areas, pressure fluctuation spectrum in each tap, and Strouhal number, this paper reveals the micro-characteristics of double vortex vibration area. This investigation indicates the possibility that occurrence of high-order vortex-induced vibration in streamline-like bridge section can be forecasted by analyzing surface pressure fluctuation spectrum of models; what is more, it is predicable to analyze the proportion of energy for the amplitude of model. Due to the same Strouhal number at same attack angle, we can decide whether the critical wind speed is lower than designed through forecasting critical wind speed of vortex-induced vibration under high speed wind.

KEYWORDS: Bridge engineering, Vortex-induced vibration, Wind tunnel test, Pressure fluctuation, High-order

1 INTRODUCTION

Contrast with vortex-induced vibration occurred in low wind, flutter attracts more attention rather than vortex-induced vibration under high speed wind in academic circles for a long time. With a lower critical wind speed in low-order modal, vortex-induced vibration takes a long time to accumulate energy. On the other hand, since vortex-induced vibration accumulates energy fast with a high critical wind in high-order modal ^[1], it is possible to stimulate vortex vibration in a short time and even cause aerodynamic instability. Therefore, concentration should be paid on high frequency vortex-induced vibration.

Second-order or higher order modal vortex-induced vibration has been found in the wind tunnel test of Tokyo Bay Aqua-Line Bridge ^[2]. For Jiaojiang Second Bridge, vortex-induced vi-

bration appeared twice in high speed wind range from 19m/s to 27m/s in +3 attack angle; torsion vortex-induced vibration appeared twice only in high speed wind range from 32m/s to 36m/s [3]. Except for vortex-induced vibration in base-order modal, there is possibility occurring vortex-induced vibration in the situation that critical wind speed is less than designed. Therefore, studying vortex vibration performance of common streamline-like section of long-span bridges, this paper introduces vortex-induced vibration phenomena under high speed wind, using time-history pressure of surface taps to analyze vortex vibration performance of the section.

2 TEST BACKGROUND

Taking a bridge as an example, the section deck model was tested in CA-1 wind tunnel at Chang'an University. In the scale of 1:25, the model is placed aluminum alloy skeleton inside, covered by hard plastic, filled in bubble, with the width of 1.2 meters.

Vibration test and pressure test were conducted simultaneously. Fig.1 shows the arrangement of model in wind tunnel. Hanged by springs, two-dimension rigid section model is used for vibration test, with two supporting arms to limit the degree-of-freedom only in vertical and torsion. Depending on vibration signal sent from four acceleration sensors installed at rigid supporting arms, we can simulate the frequency in damp ratio of 0.5% and wind speed ratio of 1:4.

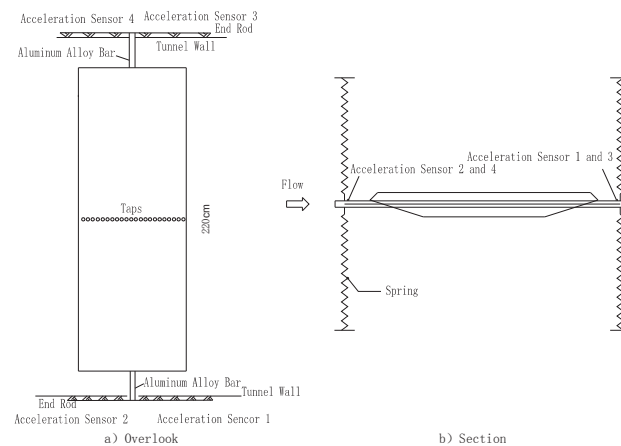


Fig.1 Arrangement of wind tunnel test

With 88 taps in the middle, which each diameter is 1mm, the model can meet the requirement of pressure test. Fig.2 displays the distribution of surface pressure taps.

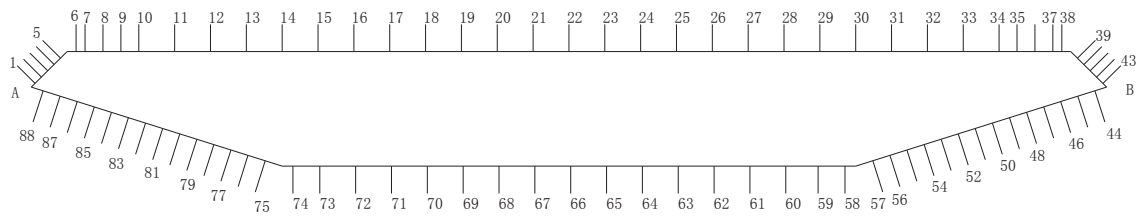


Fig.2 Taps distribution

We tested the model in the uniform flow at attack angles which were $+5^\circ$, $+3^\circ$ and 0° . The results demonstrates that vortex-induced vibration occurred when attack angle was $+3^\circ$, and there were two areas of vortex vibration. Accordingly, this paper studies the two areas in the condition of $+3^\circ$ attack angle.

2.1 Relationship between Wind Speed and Amplitude

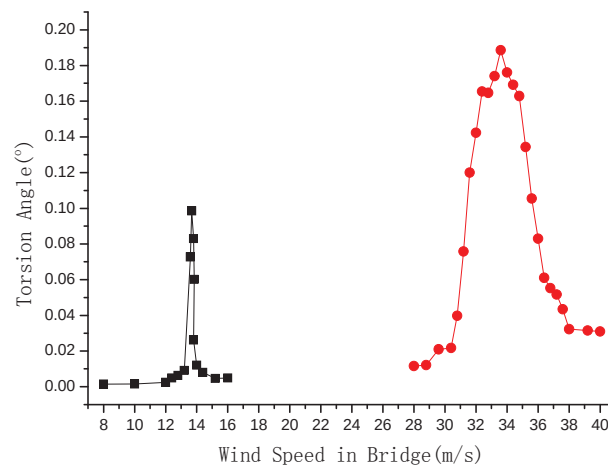


Fig.3 Relationship between amplitude and wind speed

Fig.3 shows the relationship between amplitude and wind speed. The amplitude here means standard deviation of time-history torsion angle under each wind speed. From Fig.3, vortex-induced vibration occurred twice when the wind speed ranges from 8.0m/s to 40.0m/s. The first one occurred in low wind speed from 12m/s to 16m/s. The second occurred in high wind speed, which range is 29.6m/s~40m/s. Apparently, the range of vortex vibration is wider under high speed wind, and the amplitude difference is more as well. The first maximum amplitude occurred when the wind speed was 13.6m/s under torsion angle of 0.1° , and the second maximum amplitude occurred when the wind speed was 33.6m/s under torsion angle of 0.19° , which shows the difference between two maximum amplitude is almost double. Since the speed range of the sec-

ond vortex vibration is 29.6m/s~40.0m/s, which is contained in the range of checking wind speed of the bridge, there is great possibility of occurring vortex vibration in reality.

2.2 Spectrum

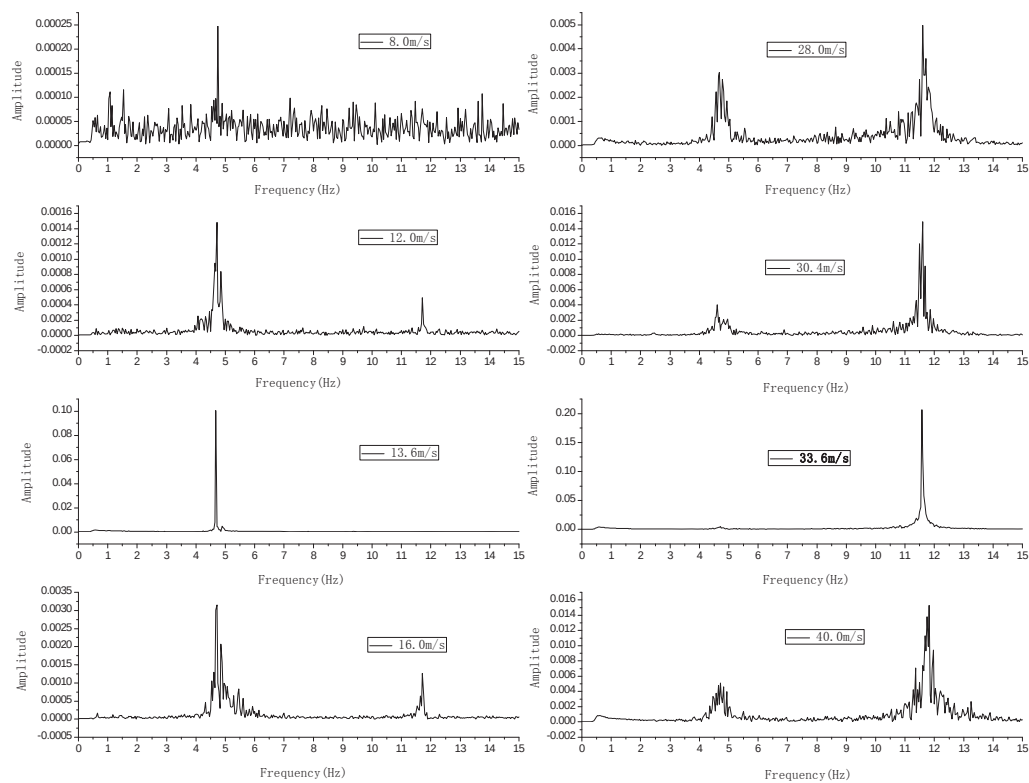


Fig.4 Torsion vibration spectrum

Fig.4 shows vibration spectrum of the model under eight different speeds of wind, including different wind speeds when the model was vibrationless, beginning vortex vibration, appearing the maximum amplitude, and has finished vortex vibration. Following the increase of wind speed, the vibration is getting intense when the frequency around 4.7Hz to 11.6Hz in two vortex vibration area. The dominant frequency is 4.7Hz in first vibration area, and is 11.6Hz in the second. After that, the vibration grows to be much intense, which becomes the max in the wind speed of maximum amplitude. The frequency becomes complex after the vortex-induced vibration ended, which indicates that the model restarted normal vibration. Containing high level of energy, the two vortex-induced vibration shows similar spectrum, with the frequency of 4.7Hz and 11.6Hz. When the wind speed is low, energy of the model increase gradually since 4.7Hz

vortex shedding frequency is same with the first-order torsion frequency; when the wind speed is high, the same phenomenon happened in the frequency of 11.6Hz.

2.3 Spectrums of each tap pressure fluctuation

The spectrum of time-history pressure reflects the characteristic of pressure fluctuation at each surface tap, and indicates the relationship between surface pressure and vibration^[5].

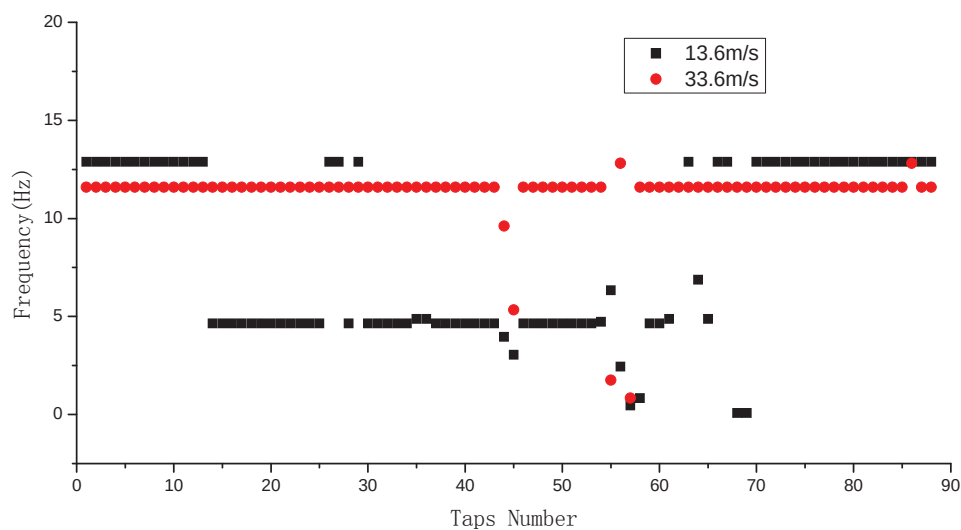


Fig.5 Frequency at the highest amplitude in spectrum

Fig.5 shows the frequency at the highest amplitude in pressure fluctuation spectrums. Only 1/2 surface taps shows 4.7Hz dominant frequency, with most of the other half centers in high frequency, and a small part disperses in different frequency, when the first vortex-induced vibration occurred (13.6m/s). Almost the all surface taps shows 11.6Hz dominant frequency when the second vortex-induced vibration occurred (33.6m/s).

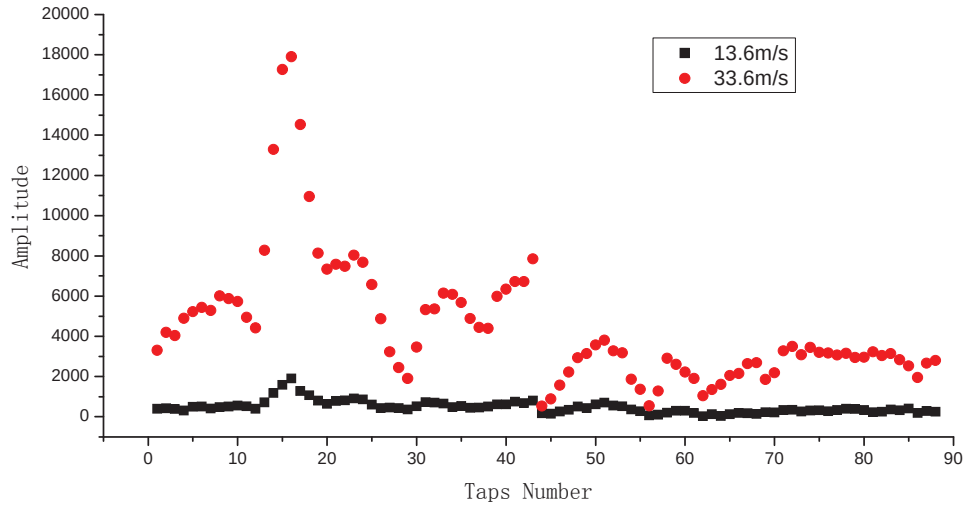


Fig.6 Amplitude of each tap vortex shedding frequency

Fig.6 depicts the spectrum amplitude of the vortex shedding under the wind speed of 13.6m/s and 33.6 m/s respectively. It is observed that the energy of the vortex shedding of the second spectrum amplitude is significantly bigger than that of the first one, which is also the case in Fig.5. This is because most of the excellence frequencies concentrate on vortex shedding frequency under the wind speed of 33.6m/s, which is dispersed under 13.6 m/s. Therefore the energy of vortex frequency is also dispersed under the wind speed of 13.6 m/s, which leads to a significantly smaller amplitude.

The above analysis reveals that airflow spiral produced by airflow crossing the section contains a variety of energy frequencies. When one vortex frequency corresponds with the frequency of the structure, vortex-induced vibration occurs. The amplitude of vortex-induced vibration is influenced by the proportion of energy of vortex frequency, and the energy of vortex frequency is determined by the frequency composition of all vortex and its degree of concentration in section tail. To illustrate, energy concentrates around 4.7 Hz and 12.5 Hz to a large extent under the 13.6 m/s wind speed, which incurred vortex-induced vibration at the structure frequency of 4.7 Hz. However, since some energy around the vortex shedding around 12.5 Hz is dispersed, the amplitude under the wind speed of 13.6m/s is significantly smaller than that of 33.6m/s. Meanwhile, since vortex shedding frequency consists of some high frequency, it is likely to bring out structure high frequency vortex-induced vibration: the structure experiences another vortex-induced vibration under the wind speed of 33.6m/s.

2.4 Strouhal Number

Under certain conditions, fluid on the surface will induce interchanging vortex shedding, which puts merged objects in the fluid under a force vertical to the flow. Both the direction and magnitude of the force change in a complicated manner with time. Its main frequency and vortex shedding frequency f and incoming flow velocity U , the characteristic size of the objects D meets Strouhal relationship.

$$S_t = \frac{fD}{U} \quad (1)$$

Fig.4 shows the main frequency and corresponding wind speed of the two vortex-induced vibration, which could be used to calculate the Strouhal number St . according to Eq.2. In the calculation, the characteristic size is the height of the beam. The Strouhal numbers in the two vortex-induced vibrations are listed in Table.1.

Table.1 St . Number of two vortex-induced vibration

No.	Test Wind Speed (m/s)	Vortex Shedding Frequency (Hz)	St . Number
1	3.4	4.7	0.165
2	8.4	11.6	0.165

Table.1 tells us that under the same attacking angle, the St . Number is fixed. Provided that there is a large component of high frequency vortex in the wake, a preliminary prediction of vortex vibration critical wind speed could be made according to the St . Number obtained in low wind speed, which casts light upon the whether the structure is safe.

3 CONCLUSIONS

- Time-history surface pressure is very informative. According to an analysis into the frequency composition of section surface pressure spectrum, a preliminary prediction to the possibility of vortex-induced vibration in high wind speed and its amplitude could be achieved.
- A disturbance of the concentration of each tap pressure fluctuation dominant frequency on first-order torsion frequency, which causes a dispersion on different frequencies, could weaken the amplitude of vortex-induced vibration.

4 REFERENCES

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