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Study on aerodynamic nonlinear characteristics of vertical vortex vibration of typical open section

Ma zhenxing[1], Li Jiawu[2]

[1]School of Highway Chang'an University, Xi'an Shaanxi province, China, 2019021027@chd.edu.cn

SUMMARY:
As a typical bluff body section, the Π type open section has poor aerodynamic stability, which is easy to cause the vortex induced vibration of the structure. In this paper, the Π shaped main beam with aspect ratio B/D =10 is taken as the research object, and the vertical vortex induced vibration is studied by wind tunnel test and numerical simulation. The results show that when the upper surface of the open section is at X/B< 0.2, the average pressure on the upper surface shows a negative pressure area, indicating that there is air separation, vortex shedding, and the fluctuating pressure changes the most when the upper surface X/B=0.2.When vortex vibration occurs in the open section, there is obvious aerodynamic nonlinearity and obvious high-frequency component in the vertical vortex induced aerodynamic force. This high-frequency component can be successfully separated based on HVD method. At the same time, it is found that in different vibration stages of vortex vibration, the work of its high-order component becomes more and more obvious with the increase of vibration amplitude.

Keywords: Π-shaped beam, Wind tunnel test, Pressure and vibration measurement, Numerical simulation, Aerodynamic nonlinearity

1. WIND TUNNEL TEST SETTINGS

1.1 Model design

This paper selects a typical section form of open bridge, the model L =1500mm, width B=600mm and height D=60mm. Distributed pressure taps are arranged in the middle section of the model, a total of 82 pressure taps are arranged, and the distance between pressure taps is 10~20mm. The spring suspension system is shown in Figure 1.

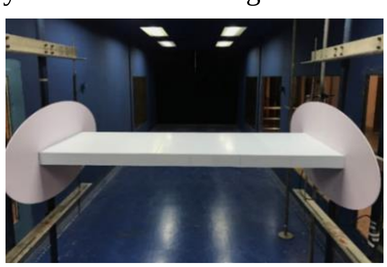


Figure 1. Segment model in CHD-01 wind tunnel

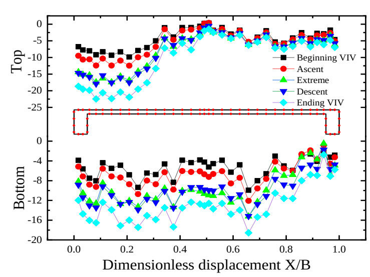


Figure 2. Mean pressure coefficients distribution during VIV

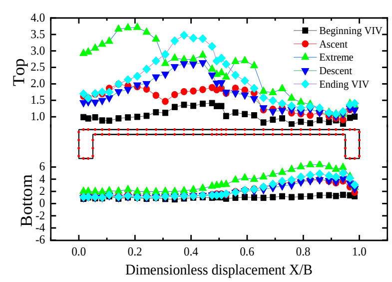


Figure 3. Distribution of fluctuating pressure coefficients during VIV

1.2 Pressure distribution characteristics of opening section

In the uniform incoming flow, under the test incoming flow wind speed of 1m/s-10m/s, the vortex vibration performance of the section is studied at the 0 ° angle of attack. The average pressure and fluctuating pressure distribution on the surface of the open section are shown in figures 2 and 3:

1.3 Amplitude frequency characteristics of vortex induced force

Figure 4 shows that the vortex induced aerodynamic force fluctuates with time, which is not a single frequency sinusoidal curve. After spectrum analysis, as shown in Figure 4c, it is found that under $U/F_bD = 20.08$, the vortex induced vibration curve and the vortex induced force time history curve have the same excellent frequency of 3.36hz (fundamental frequency of 3.32hz), but there is a second harmonic component with an obvious frequency component of 6.7hz in the vortex induced force time history, which reflects that the vortex induced force has obvious nonlinearity.

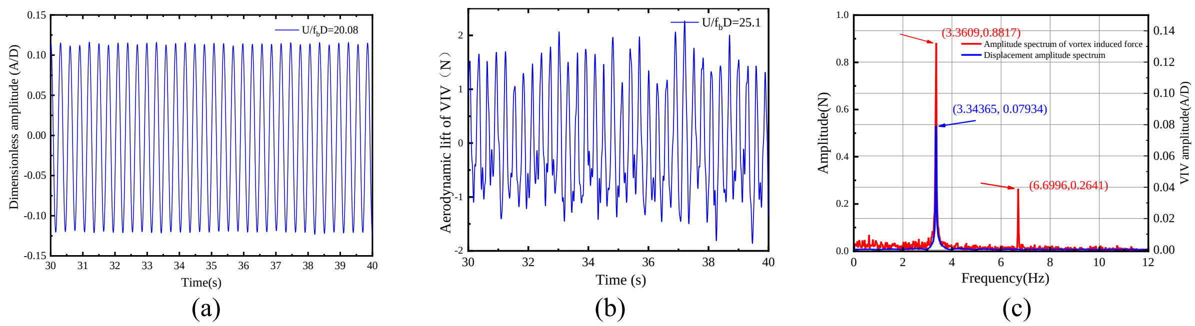
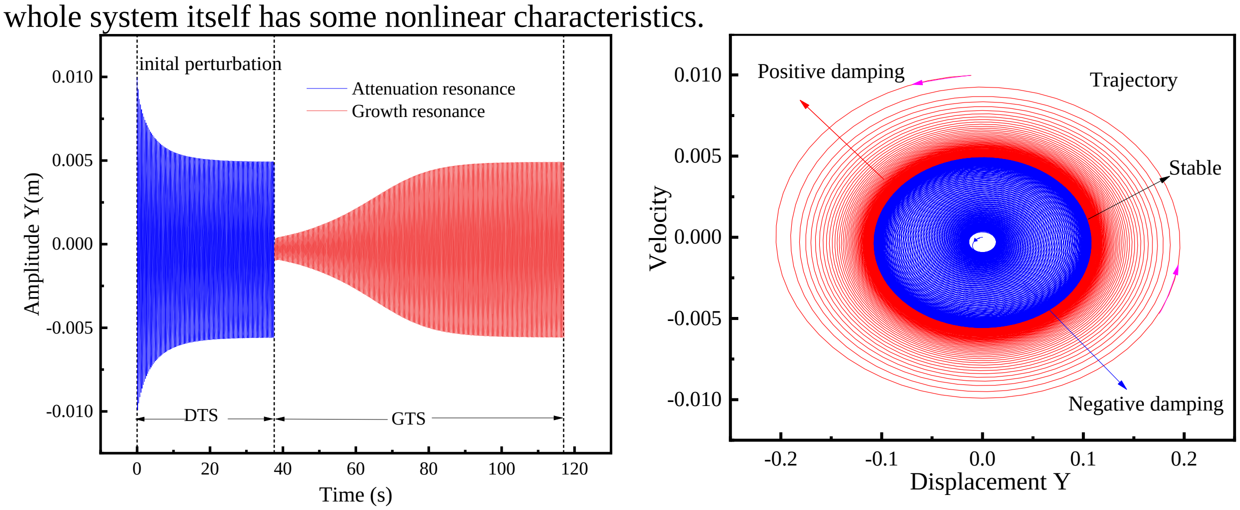


Figure 4. Time history of displacement and vortex induced force at extreme of VIV (U/f_bD=20.08)

2. NUMERICAL SIMULATION OF ORIGINAL SECTION

2.1 Self-limiting vibration characteristics of the VIV

VIV has typical self-limiting characteristics. On the phase plane, t the steady state vibration of the system behaves as a closed limit cycle, which indicates that it is a periodic attractor. Any motion state of the system near this periodic attractor will eventually be attracted by it. This is a typical limit cycle oscillation (LCO) phenomenon. As shown in Figure. 5(a), When the system is subject to large initial disturbance, its structural amplitude will slowly decay to a stable state (DTS). When released from zero displacement, its amplitude will slowly increase to stable amplitude stage (GTS). It shows that both DTS and GTS processes converge to the same amplitude. Figure 5 (b) shows the phase diagram of the VIV system. It can also be seen from Figure 5 (b) that the VIV system converges to a stable LCO amplitude, but the closed track is elliptical, indicating that the whole system itself has some nonlinear characteristics.



(a) Time history (b) Phase diagram

Figure 5. LCO phenomenon under different initial excitation

2.2 Aerodynamic components

In this section, the Hilbert vibration decomposition method is adopted (HVD). Compared with the traditional empirical mode decomposition EMD method, the HVD method can accurately separate the high-order components in the vortex vibration system, as shown in Figure 6 below.

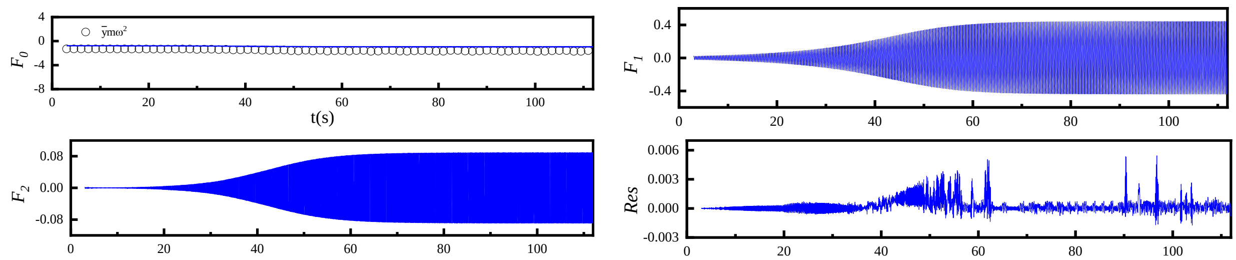
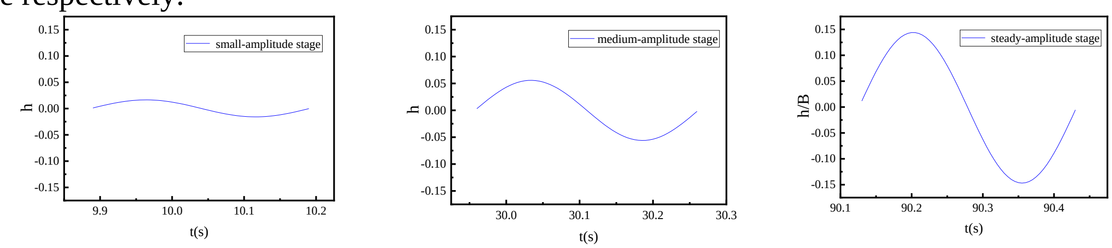


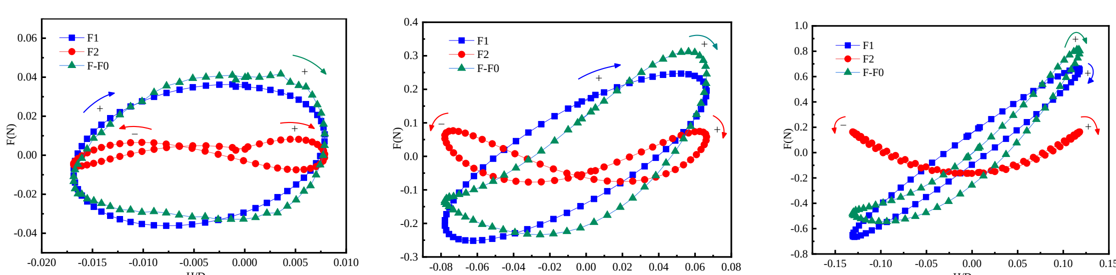
Figure 6. Aerodynamic lift component

2.3 Characteristics of aerodynamic work in vortex vibration

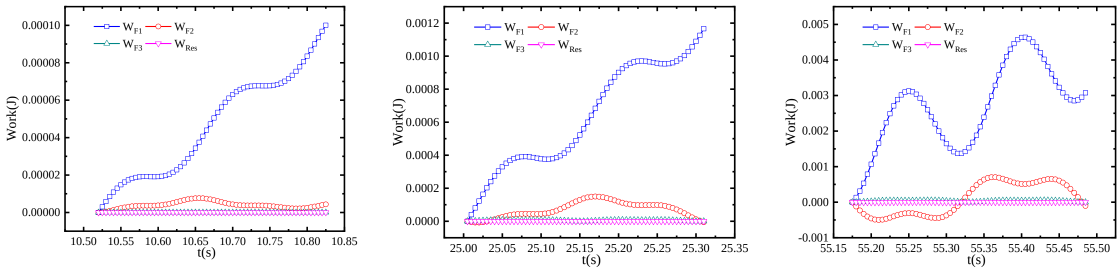
In this paper, three typical vibration curves in the development of vortex vibration are selected, as shown in Figure 7, which correspond to small amplitude stage, medium amplitude stage and stable stage respectively.



(a) Displacement time history of the vertical vibration



(b) Hysteretic curves at different stages of VIV



(c). Accumulated work of the aerodynamic components

Figure 7. Characteristics of self-excited lift component in a typical vibration period of an open section (V* =22.1)

3. CONCLUSION

1、The wind tunnel vibration pressure measurement test shows that when the average pressure X/B is less than 0.2, the upper surface presents a negative pressure area, the air flow separates, the vortex falls off, and then remains stable, indicating that there is no reattachment phenomenon. When the fluctuating pressure is in the area of 0.1＜X/B＜0.7, the fluctuating pressure changes violently. At the extreme point of vortex vibration, when X/B=0.2 on the upper surface, the fluctuating pressure changes the most, which also reflects that this is the position where the vortex falls off.

2、At different stages of vortex induced vibration, the higher-order components of vortex induced force have a certain dependence on the amplitude of vortex induced vibration. From the perspective of vortex induced aerodynamic work, with the increase of amplitude, the work done by the higher-order components becomes more and more obvious.

3、For the research object in this paper, from the initial state of VIV to the vibration state with stable amplitude, the aerodynamic nonlinear effect of the section is significantly enhanced. HVD method can successfully separate the different components of aerodynamic force. Among them, the first-order aerodynamic component does positive work in the whole vibration period, while the second-order aerodynamic component produces a complex hysteresis curve with a shape similar to 8. In addition, the influence of the third-order component and other components on the VIV system can be ignored.

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