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Investigation of the vibration and fluid characteristics in a 5:1 rectangular section

Jiaying Wang[1], Xiaodong Zheng[2], Feng Wang[3], Jiawu Li[4]

[1]*Chang'an University, Xi'an, China, Wjying959@chd.edu.cn*
[2]*GBA Specially Long Span Bridge Maintenance Technology Center, Guangzhou, China, xd_zheng@outlook.com*
[3]*Chang'an University, Xi'an, China, wf@chd.edu.cn*
4Chang'an University, Xi'an, China, ljw@gl.chd.edu.cn

SUMMARY:
In this study, a 5:1 rectangular section was taken as the research object. An attempt was made to use the ERA-based reduced model to find if the rectangular section also conforms to two patterns vibration mechanisms. POD and CFD were used to study the vertical oscillation characteristics of the 5:1 rectangular section. The results showed that the vertical oscillation of the rectangular section could be divided into two patterns according to the oscillation characteristics: "resonance-induced vibration" and "competition-induced vibration". That is consistent with the existed researches. For different forms of vibration, the speed-displacement curve and energy of the system change differently for different forms of vibration, but the phenomenon in same vibration state is similar. The fluid field exists positive symmetry mode and antisymmetry mode. For different states, the vorticity presents different phenomenon. The POD shows that the energy presents a stepwise form decline with the modes. In a same step, the modes have quite energy to compete with each other.

Keywords: Vortex-induced vibration, CFD, POD

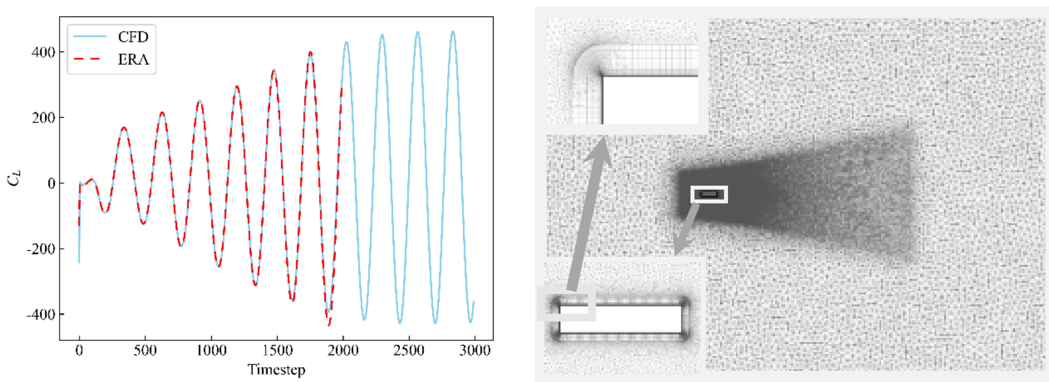
1. GENERAL INSTRUCTIONS

Vortex-induced vibration (VIV) has attracted much attention in many engineering fields. For the field of bridge wind engineering, because of the complexity of the section, it is often difficult to study the vibration mechanism of the section. In order to understand the VIV characteristics, many scholars have carried out a series of studies on the different sections. And the researches have made some achievements. The fluid patterns leading to the vertical oscillation of a rectangular section and suggested four different vortex structures as the influence factors for structural oscillation (Naudascher,1993). The van der Pol oscillator model was introduced to describe fluid motion and found that the natural frequency of a structure captures the vortex shedding frequency in its frequency lock-in region (De Langre,2006). An aeroelastic system using linear state-space system theory was attempted to construct (Zhang et al., 2015,2019, Mittal, 2016). Although some achievements have been made in the study of VIV response, the specific vibration characteristics and inducing mechanism are not clear.

In this study, the VIV response of the 5:1 rectangular section was studied using CFD and POD. The mass ratio and damping ratio were changed to study the change of speed-displacement curve and variation in energy. Vorticity was analyzed under different reduced wind speed. And the fluid characteristics was analyzed by POD.

2. METHODOLOGY

By comparing the lift coefficient obtained by CFD with lift coefficient obtained by reduced-order model, the rectangular section also obeying the vibration mechanism of two patterns of vortex-induced vibration. Based on this phenomenon, the vertical vortex-induced vibration of rectangular section was studied by CFD and POD.



a) Simulation effect b) Mesh

Figure 1. Mesh and simulation effect

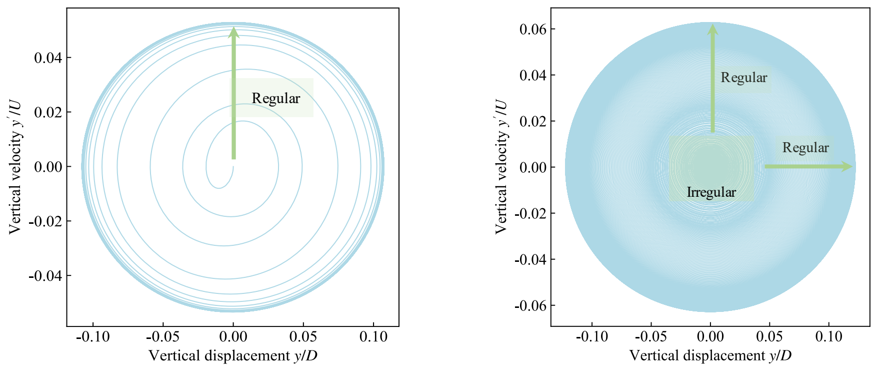
In the numerical calculation process, the turbulence was set at 0.5% and a turbulence viscosity ratio of 10% was used to activate the turbulence model. The SST k-ω model can automatically switch the solution method according to the size of y+. Thus, the SST k-ω model was adopted in this study considering its strong inclusiveness. B was set at 0.3m and D was set at 0.06m to facilitate comparison with previous studies (LI, X.T., 2019). In addition, this study used a hybrid mesh composed of triangles and quadrilaterals, as shown in Fig.1. The quadrilateral mesh was used to analyse the boundary layer, and the mesh was encrypted around the rectangular section and near the wake area. The cases are as shown in Table 1.

Table 1. Structural motion parameters.

Case	Mass ratio	Damping ratio	Limit circle and energy (CFD)	Static and vibration (POD)
1	6.375	0.0045	6.88; 8.67; 9.56; 10.54; 11.00; 12.19	6.88; 9.56; 11.00; 12.19
2	6.375	0.000156	U*=6.88; 8.67; 10.54; 12.19	\
3	0.2205	0.0045	U*=8.67; 10.56; 12.19	\

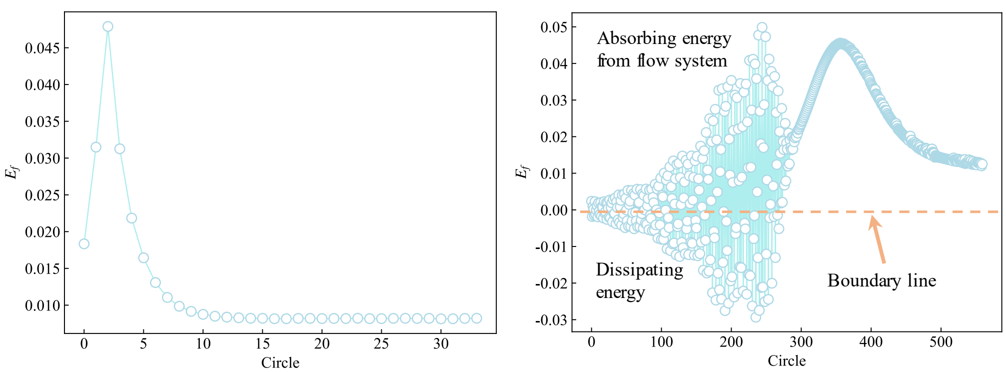
2. RESULT AND DISCUSSION

Fig.2 and Fig.3 show the Speed-displacement curve of vertical vibration and variation in energy respectively. Under different parameters, the speed-displacement curve and energy present different forms. For low mass ratio, the curve is neatly dense from the center to the outside and the energy quickly reaches the stable state. It reflects the mutual capture of structural vibration frequency and vortex shedding frequency, that is “Resonance-induced vibration”. For low damping ratio, the curve is relatively irregular at the initial stage; however, it begins to become ordered and dense towards the outside of the circle after a certain period of development. And the energy alternates between positive and negative in the early stage, and then becomes stable gradually. It reflects the mutual competition of structural mode and fluid mode. That is “competition-induced vibration”.



a) m=0.2205, ζ=0.0045 b) m=6.375, ζ=0.000156

Figure 2. Speed-displacement curve of vertical vibration (U*=12.19)



a) m=0.2205, ζ=0.0045 b) m=6.375, ζ=0.000156

Figure 3. Variation in energy (U*=12.19)

Fig.4 shows the Vortex for two patterns of vortex-induced vibration. For static state, the vorticity of the two patterns of vortex-induced vibration is slightly different, but the form and magnitude are basically the same. For the vibration state, the difference of the trailing vorticity can be clearly observed for the two patterns of vortex-induced vibration. Compared with competition-induced vibration, resonance-induced vibration has shorter trailing vortex shedding. Compared with the static state and the vibration state, the distribution of vorticity on the upper and lower surfaces and leeward side for the rectangular section is different, and the shedding of the tail vorticity is longer in vibration state. Fig.5 shows the POD analysis. The energy is distributed in a stepwise form as the modes increase. The energy of the second-order mode component is equivalent to that of the third-order mode component, and the energy platform shows a step-like distribution. Considering that competition-induced vibration is caused by modal competition, this is consistent with the form shown in Fig. 3. Additionally, the alternating modes of positive symmetry and antisymmetry constitute the dynamic characteristics of fluid field.

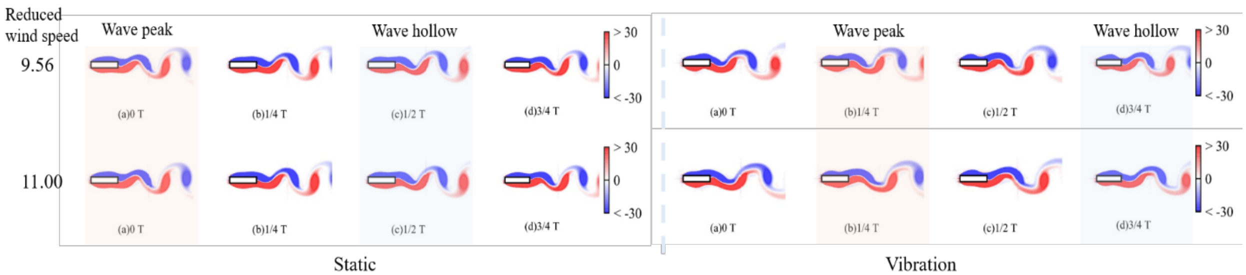
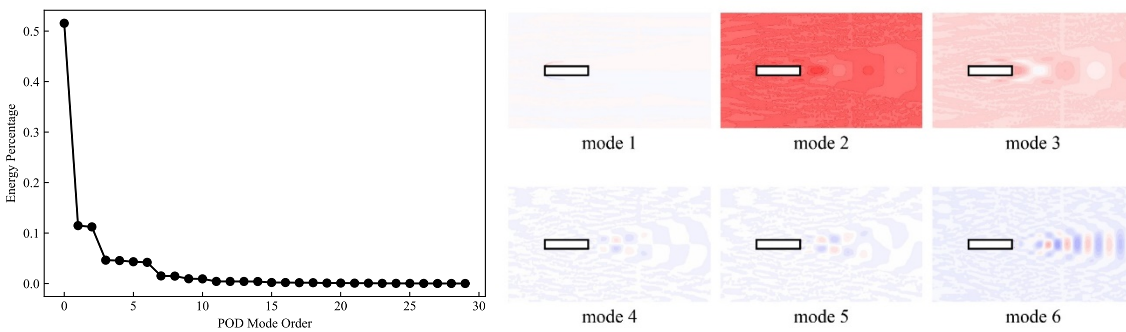


Figure 4. Vortex for two patterns of vortex-induced vibration (Static and vibration)



a) Mode energy ratio

b) The first six modes

Figure 5. POD analysis (U*=6.88)

3. CONCLUSION

Based on the analysis of 5:1 rectangular section, the characteristics of two patterns of vortex-induced vibration were understood under different situation. The CFD method was used to study the rectangular section. The speed-displacement curve and the energy distribution characteristics of the two vibration patterns are obviously different. For the competition-induced vibration, the energy has obvious competition at the initial stage, and after a long period of competition, the energy becomes stable. And the speed-displacement curve change from irregular to regular. The POD method was used for modal decomposition of the fluid field. The modal energy presents a stepped distribution. The length of energy platform increases with the increase of the modal order. The modal energy in the same platform is similar and that make the modes own a capacity for competition. Additionally, the fluid field exists positive symmetry mode and antisymmetry mode.

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