博士論文（要約）

Numerical study of wind-induced vibration and aerodynamic suppression of bridge cables

(橋梁ケーブルの自励振動と空力制振に関する数値予測)

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The circular cylinder cables are widely used on suspension bridges and cable-stayed bridges. They are sensitive to wind load because of their flexibilities and low damping ratios. The single cable suffers from vortex-induced vibration (VIV) when the structural natural frequency is consisted with the vortex-shedding frequency, and the parallel cables suffer from wake galloping that the downstream cable is vibrated by the wake of the upstream cable. These two kinds of wind-induced vibration are often of primary concern in bridge engineering and greatly affects the performance and fatigue life of the bridge cables. In the previous research, wind tunnel experiment is the main tool to study these phenomena. With the development of computational technique and resource, Computational Fluid Dynamic (CFD) is considered as a powerful tool to investigate the fluid-structure interaction. Numerical simulation by CFD can provide not only dynamic response of structures, but wind force and visible flow flied as well, which are helpful for phenomenon investigation and mechanism explanation. In this thesis, CFD numerical simulation is used to study the phenomena of VIV and wake galloping of circular cylinder cables.

To suppress the VIV and wake galloping of circular cylinder cables, traditional mechanical dampers and aerodynamic countermeasures such as helical wires were used. Compared with traditional mechanical dampers, helical wires have fewer restrictions. They can be used when the distance between bridge girder and cables are large and the traditional mechanical dampers are hard to install. However, current design practices of helical wires for vibration suppression rely heavily on the model testing, because the vibration control mechanism and the effect on aerodynamic forces of such fluid dynamic countermeasures has not been fully understood and it is hard to make a guidance to select suitable configurations of helical wires for the circular cylinder structures experiencing similar problems. More comprehensive study on this issue is also investigated in this thesis to concern the effectiveness and mechanism of helical wires on aerodynamic forces and wind-induced vibration suppression for bridge cables.

In present study, firstly the three-dimensional numerical model is proposed for the simulation of VIV and wake galloping of circular cylinder bridge cables. Then the VIV of single cable with single-degree-of-freedom (SDOF) and two-degree-of-freedom (2DOF) systems are simulated. Different numerical conditions are tested and the accuracy of numerical model is validated by experiment data. After that the effect of mass and spacing ratios on wake galloping of the tandem cables is studied by the validated numerical model. Finally, the effect and mechanism of helical wires on aerodynamic forces and vibration suppression for circular cylinder structures is illustrated. The arrangement of each chapter of this thesis is as follows:

In Chapter 1, the study background of wind-induced vibration of bridge cables is introduced briefly. The previous researches on VIV and wake galloping of circular cylinder structures are summarized. The objectives of this study are described.

In Chapter 2, the numerical model used in this research is introduced. The governing equations and solution schemes are given. The computational domain and mesh are described and the modelling of oscillation system is explained.

In Chapter 3, the vortex-induced vibration of single circular cylinder is simulated. The effect of model length and side boundary on the prediction accuracy of aerodynamic forces are tested and the numerical model is optimized and validated by experimental data. The characteristics of vibration and aerodynamic forces of single circular cylinder in water and in air are studied through two dimensional and three dimensional models with single-degree-of-freedom and two-degree-of-freedom systems. It is found the maximum amplitude of VIV single cylinder is under-estimated by 2D k-ω model while well predicted by 3D LES model for both SDOF and 2DOF systems.

In Chapter 4, the effects of mass and spacing ratios on the wake galloping of tandem circular cylinders are investigated, in which the upstream cylinder is fixed and the downstream one is free to respond in the transverse direction. The characteristics of wake galloping are systematically studied for the cases with mass ratios of m^*=1.8, 200 and spacing ratios of x_0/D=4, 8, 12. It is found the critical velocity of wake-galloping of tandem circular cylinders increase as mass and spacing ratios increase. A critical velocity to identify the divergent regime of wake galloping of tandem circular cylinders is then derived as a function of mass ratio and lift coefficient slope using a wake-stiffness-based model. This critical velocity of is used to explain the effects of mass and spacing ratios on the wake galloping of tandem circular cylinders.

In Chapter 5, the effect of helical wires on VIV and wake galloping suppression of circular cylinders is checked. The VIV and wake galloping amplitudes of circular cylinders are found to be suppressed by 4-started helical wires of pitch ratio P/D=8 and diameter ratio d/D=0.1. The lift force coefficient on cylinders with helical wires is reduced and the mechanism of such effect is explained by the reduction of lift force spanwise correlation due to the enhance of three-dimensionality of flow field for the single cylinder and disturbance of the gap flow between tandem cylinders. The aerodynamic damping is predicted by forced vibration simulation. It is found the aerodynamic damping of bare cylinder is negative if the forced vibration amplitude is lower than the free vibration amplitude and make the total system damping negative. The helical wires generate positive aerodynamic damping and suppress the VIV and wake galloping of circular cylinders.

In Chapter 6, the conclusions obtained from this study are summarized.