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Numerical investigation of flow field and vibration of twin-mast atop of Saige Plaza Building

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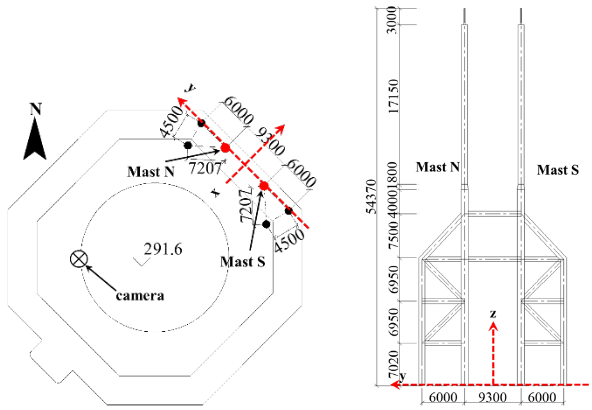
SUMMARY:
The obviously vortex-induced vibration (VIV) of two masts at the top of Saige Plaza Building in Shenzhen was observed under mild wind speed conditions. The wind speed and direction on the roof of the building are analysed according to the meteorological data near the building and the numerical simulation of urban wind field. The computational fluid dynamics (CFD) model is established to compute and analyse the aerodynamic characteristics and wake mode around double masts atop of the building. Vortex-induced vibration of two masts on the roof is simulated by fluid-structure coupling method. The results show that the wake mode of twin masts with a large distance is a mixed mode, and both anti-phase and in-phase synchronous vortex shedding occurring behind the masts. This work simulates the flow characteristics around the twin masts atop of Saige Plaza building and reduces VIV phenomenon of the twin-mast.

Keywords: large spacing twin-mast, flow around circular cylinder, vortex-induced vibration

1. INTRODUCTION

Many high-rise buildings have been built with mast structures installed atop of the building for functional requirements. Due to the large slenderness ratio of the mast structure, significant vortex-induced vibration is prone to occur under certain wind speed conditions. This continuous vibration will cause fatigue damage to the mast structure and affect its service life (Huang et al., 2021). The vibration of the mast could even cause the vibration of the building when the vibration frequency of the mast is close to the natural frequency of the building (Huang et al., 2022). At noon on May 18, 2021, the occupants in Saige Plaza Building, Shezhen, experienced the obvious building motions and the masts atop of the building were found in vibration. Numerical simulation of flow fields around the roof masts has been carried out to investigate the aerodynamic actions on the twin-mast structure during that period on May 18, 2021. Fig.1 shows the size of the mast structure on the Saige Plaza Building. The mast on the north side of the roof is denoted as Mast N while the mast on the south side is denoted as Mast S.

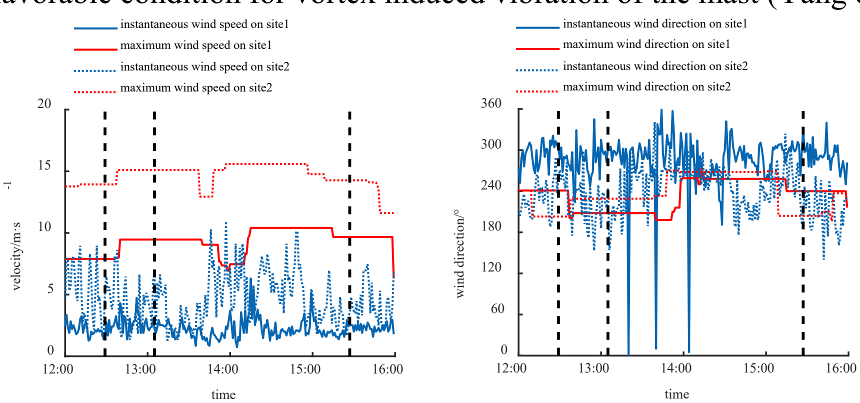


(a) plan view (b) front view

Figure 1. Building plan and the front view of mast (unit: mm).

2. OBSERVATION OF WIND FIELD AROUND THE BUILDING

There are two automatic meteorological stations near the Saige Plaza Building. One is placed at a height of 65.3 meters, and the other is located at the top of the building with an altitude of 298.7 meters. The wind speed and direction data during the vibration of the top mast were recorded at both two stations. The instantaneous wind speed and direction as well as peak wind speed and its direction at two stations are shown in Fig. 2, where the black dashed line is the moment when the masts on the roof of the building vibrates. According to the data recorded at site 2, when the vibration occurred, the maximum wind speed at the mast height was between 7m/s and 13m/s, and the instantaneous wind speed was between 4m/s and 9m/s. The maximum wind speed during vibration was between 12m/s and 17m/s, and the instantaneous wind speed was between 6m/s and 11m/s. In addition, the instantaneous wind direction angles recorded at the two stations during the incident period are between 220° and 270°, i.e., mainly west or southwest wind, which is in a favorable condition for vortex induced vibration of the mast (Yang et al. 2023).



(a) wind velocity (b) wind direction

Figure 2. Wind speed and direction data on May 18, 2021 from meteorological stations.

3. CFD SIMULATION OF FLOW FIELD AROUND TWIN MASTS

3.1. CFD Simulation settings

As shown in Fig.3, a three-dimensional computational domain is established for CFD simulation of flow field around twin masts. The computational domain size is 60m (length) × 20m (width) ×

22.95m (height). In order to ensure that the Reynolds number is the same as the actual situation, the scale ratio is 1:1. The boundary conditions on the lateral sides of the computational domain are set as symmetrical boundary conditions. The inlet boundary condition is set as the velocity-inlet boundaries the velocity inlet. In order to accurately simulate the flow around the masts, the inlet wind speed is defined as 11.21 m/s. In order to simplify the simulation, only the incoming flow perpendicular to the mast plane is considered. The inlet wind direction is perpendicular to the mast plane, and the inlet turbulence is set to 0.13. The grid size of the lateral sides is 0.2 m. The radial minimum grid size is 0.005 m. The circumferential grid size is 0.01 m. The y^+ is less than 10, which meets the law of boundary layer calculation. The total number of grids is about 8.9 million. The model grid is shown in Fig.4.

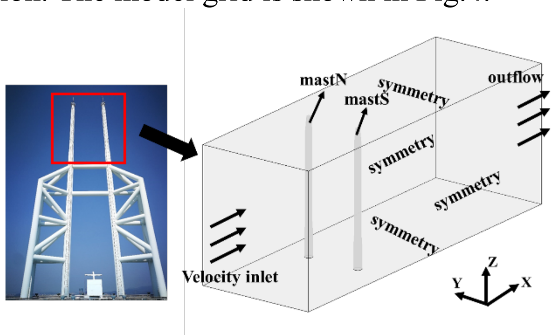


Figure 3. Diagram of computational model.

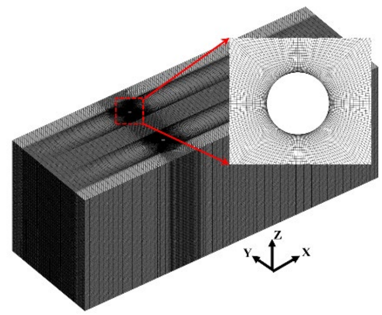
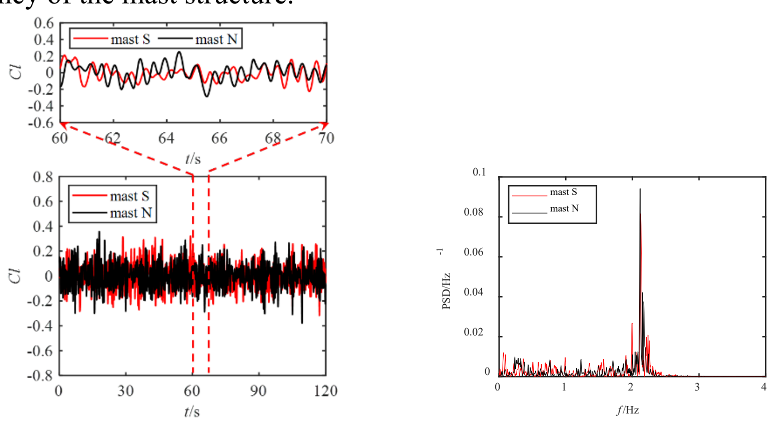


Figure 4. Mesh setting of flow simulation around masts.

3.2. Simulation results

From the time history of the lift coefficient, it can be seen that the regular shedding of the vortex on the surface of the mast leads to the obvious periodicity of the lift coefficient. In addition, by comparing the aerodynamic forces of the two masts, it was found that the two masts have both the same phase and the reverse position, indicating that the wake mode of the large spacing twin masts is in a mixed mode. And there are anti-phase vortex shedding as well in-phase synchronous vortex shedding behind masts. At the same time, the amplitude of the aerodynamic force on the two masts is also significantly different. The power spectral density diagram shows that the peak energy is at 2.12 Hz, which is the same as the fourth-order modal frequency of the mast structure.

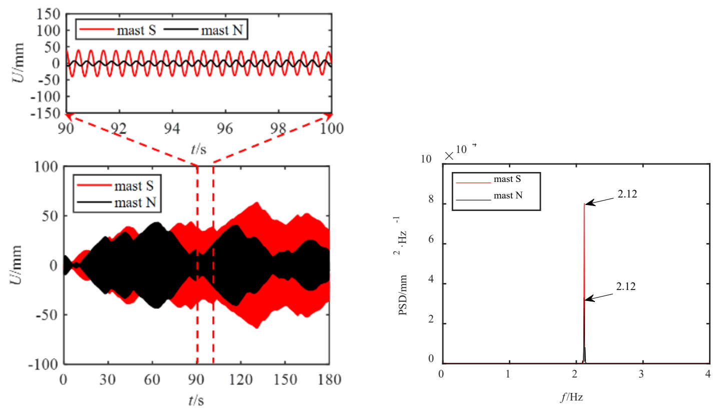


(a) time history of lift coefficient (b) power spectral density

Figure 5. Time history and power spectral density of lift coefficient.

4. VORTEX-INDUCED VIBRATION SIMULATION OF TWIN-MAST

We also carried out a fluid-structure coupling simulation to obtain the wind-induced vibrations of masts. As shown in Fig.6, the displacement of mast S is slightly larger than that of mast N. It can be seen that the energy is concentrated near the natural vibration frequency of the mast. In addition, it can be seen that there is a significant phase difference between the vibration of the two masts at each time, showing an anti-phase vibration mode. The fluid-structure coupling simulation of the twin-mast can reproduce the observed vibration of the top masts of the target building.



(a) time history of displacement (b) power spectral density

Figure 6. Time history and power spectral density of displacement of twin masts.

5. CONCLUSIONS

The meteorological observation data show that the wind speed and direction atop of Saige Plaza building favor the conditions of VIV of the twin-mast. The CFD simulation has been conducted to analyze the aerodynamic characteristics and wake modes around double masts atop of the building. It was found that both anti-phase and in-phase vortex shedding occur around the twin masts separated by a relatively large distance. Vortex-induced vibrations of two masts on the roof were calculated by fluid-structure coupling method. The calculated vibration responses of twin-mast generally agree with the vibration behavior observed during noon on May 18, 2021.

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