

directions, thus $W_\alpha < 0$. After $t=1/2T$, the MIV increases its strength as it moves to downstream. As the MIV travels to the trailing edge of upper surface, it generates a strong nose-down (negative) moment and results in a strong restoring impulse. At $t=1/2T \sim 3/4T$, the deck section is forced to rotate to a negative angle as the flow time goes on, and the self-excited moment does positive work during this process. Then, the deck section moves back to the equilibrium position at $t=3/4T \sim T$, and $W_\alpha < 0$ is also because the deck rotates in the opposite direction of twist moment. In a sense, the MIV also plays an intermediary role for the energy transfer between the structure and the wind flow. For the deck section at $+5^\circ$ attack angle, as mentioned above, the same soft flutter state is reached both from the rest and from the large initial perturbation. It indicates that the MIV can be generated spontaneously or by the initial perturbation.

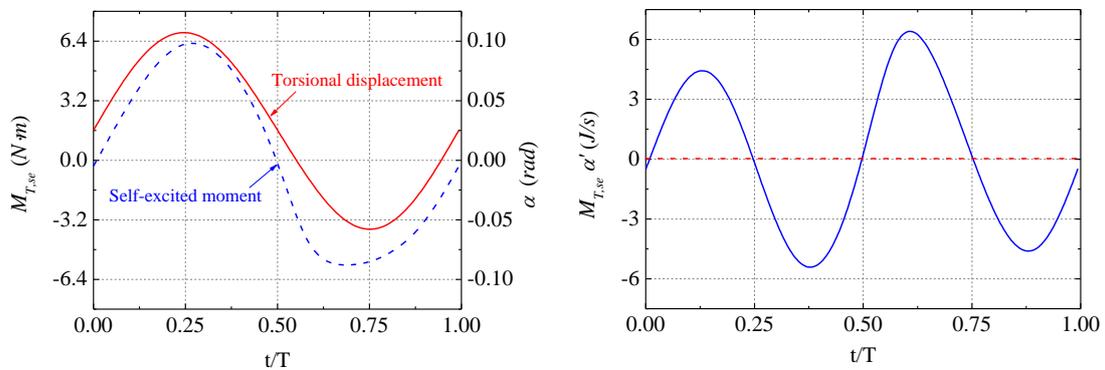


Fig. 13. Time history of aerodynamic moment, torsional displacement and associated aerodynamic power during one flutter cycle, 5° initial attack angle, $U_0 = 12 \text{ m/s}$

Below the critical wind speed of soft flutter, the MIV caused by the initial perturbation is not strong enough to preserve the motion and the deck section is characterized by attenuated vibration. At the wind speed range of soft flutter, the MIV is strong enough when it moves along the surface of the deck section to generate large aerodynamic forces. The dynamic response of the deck section develops into steady state vibration due the strong nonlinearity of MIV-induced forces. As the wind speed increases, the strength of MIV becomes higher. After the critical wind speed of hard flutter, the energy absorbed from the wind flow through the MIV is more than that dissipated by structural damping, results in the occurrence of hard flutter.

7. CONCLUSIONS

Based on *ANSYS FLUENT*, a fluid-structure interaction (FSI) model has been developed to investigate the soft flutter characteristics of a bridge deck. The accuracy of present numerical model is verified by one thin plate section with theoretical solutions. The present numerical model successfully recaptures the soft flutter phenomenon of the bridge deck. With the increase of attack angle, the deck section becomes much blunter, and it is more prone to soft flutter. The soft flutter amplitude increases gradually with the wind speed until the hard flutter occurs.

The soft flutter of bridge deck is in a bending-torsion coupled mode, and the coupled vibration frequency linearly decreases with the increase of wind speed. The motion induced vortex (MIV) generated and shed periodically on the deck surface is the fundamental cause of the soft flutter of bridge deck. A stronger MIV is generated at the leading edge of deck surface, and the width of the MIV significantly decreases with the increase of torsional amplitude. So the MIV takes a longer time to travel to the trailing edge and shed from the deck surface, leading to a longer period for soft flutter. There must exist an aerodynamic energy balance for bridge deck during soft flutter, i.e., the fluid-structure system absorbs and dissipates energy in a certain vibration region so as to achieve the balance.

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