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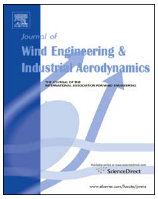

Wake control of vortex shedding based on spanwise suction of a bridge section model using Delayed Detached Eddy Simulation

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ABSTRACT

In this paper, the DDES (Delayed Detached Eddy Simulation) is applied to study the spanwise suction control effect on wind-induced effect of a static bridge deck. Isolated suction holes are arranged on the lower surface of the test model in spanwise direction, and based on previous studies of similar bluff body, a proper distance of spanwise suction was chosen to trigger or amplify the most unstable secondary instability (i.e. Mode A) in wake. The simulation results show that the suction arranged close to the wake has the best control effect on reducing the fluctuating aerodynamic forces. Due to the mean-velocity modification by isolated spanwise suction, the virtual aerodynamic shape modification is generated, which could act as spanwise perturbation to suppress spanwise vortexes. The results indicate that the spanwise suction could trigger or amplify the Mode A instability, and hence lead to the dislocation of the spanwsie vortex or even completely suppress the spanwise vortex. In addition, the spanwise suction control can surpress spanwise vortex shedding in a wide *Re* range.

1. Introduction

Due to the low rigidity and light mass, the long span bridge is more prone to subject to the vortex induced vibration (VIV), which always results in structural fatigue and visible movements of the bridge. The appearance of this kind of aeroelastic instability is closely related to the spanwise vortices in the wake of the bluff body. The axis of these vortex tubes is parallel with the spanwise direction. Also, the von Karman vortex, a kind of spanwise vortex, is the main reason introducing the drag force and fluctuating of the bluff body such as flat plate girder. Therefore, it is necessary to find a way to suppress spanwise vortex in wake so as to mitigate the VIV and reduce aerodynamic forces.

According to Choi et al. (2008), this control is classified into direct-wake control, which performs direct-wake modification in the wake of a bluff body. It includes control splitter plate (Anderson and Szewczyk, 1997; Hwang et al., 2003; Ozono, 1999), base bleed (Arcas and Redekopp, 2004; Bearman, 1967; Delaunay and Kaiktsis, 2001; Yao and Sandham, 2002), a secondary small cylinder (Kubo et al., 1999; Strykowski and Sreenivasan, 1990) and three-dimensional spanwise disturbances (Chen et al., 2013; Kim and Choi, 2005; Kim et al., 2004; Lam, et al., 2004; Naghib-Lahouti et al., 2012; New et al., 2013, 2015). There into, three-dimensional disturbances shows more efficient than the method limited in two-dimensional framework to attenuate vortex shedding for a wide range of Reynolds numbers. Therefore, its application for reducing the oscillating lift forces and reducing the drag of bluff bodies has attracted much attention (Bearman and Branković, 2004; Bearman and Owen, 1998; Darekar and Sherwin, 2001; Deshpande and Sharma, 2012; Dobre and hangan, 2004; Dobre et al., 2006; El-Gammal et al., 2007; Naghib-Lahouti and Hangan, 2010; Naghib-Lahouti et al., 2012; New et al., 2013, 2015; Owen et al., 2001). In natural environment, the bridge always subjects to much higher *Re* and turbulence intensity. In fact, the vortex shedding is also the prime mode of wake flow at high Reynolds numbers. The related dynamics remains similar to that of low Reynolds number vortex shedding. Therefore, it should be valid on control of the wind induced effect of the long span bridge in the natural environment with three-dimensional disturbances control. In addition, the traditional control methods to against VIV of bridge decks are in two-dimensional framework such as guide vane and they need installed all along the spanwise direction. While the three-dimensional control method which need install the control device at a certain distance could save a lot. Therefore, in the present study, we will check the effectiveness of three-dimensional disturbances on a bridge model.

Mitigating vortex shedding by applying three-dimensional disturbances has developed in the mid-1960s of the past century. As early as 1950s, the experimental results of Grant (1958)

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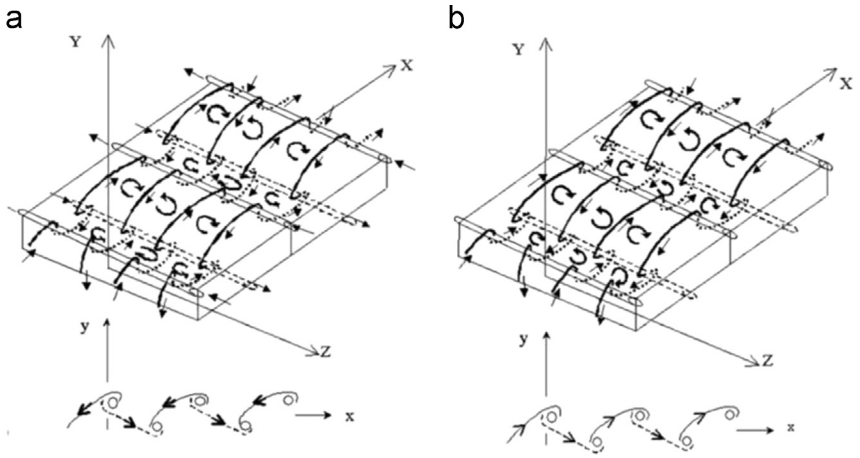

Fig. 1. Two low Reynolds number instability modes: a) Mode A and b) Mode B. Karman spanwise vortices as primary flow structures, shown as straight tubes along the *z* axis, and ribs as streamwise secondary vortices with different vorticity signs, from both upper (solid line) and lower sides(dash line) of the wake (Meiburg and Lasheras, 1988).

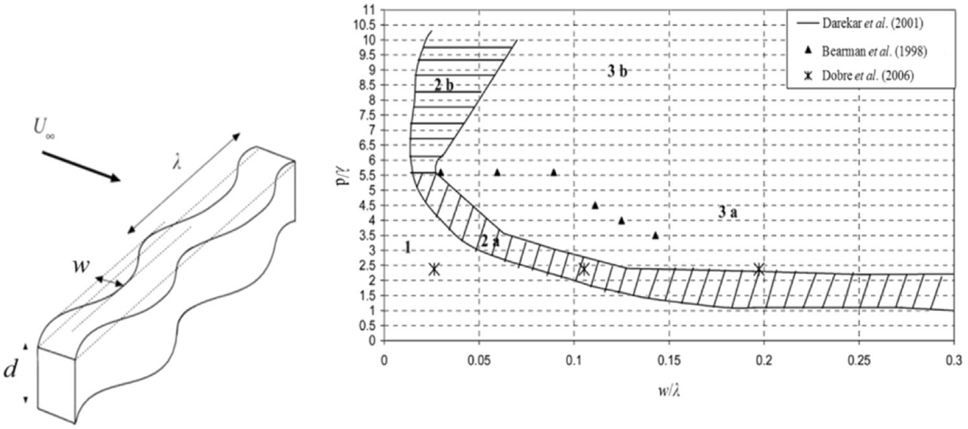

Fig. 2. Wavy square cylinders flow regimes (*d* is the length for square, *w* is height of wave, *λ* is spanwise wave length, U_∞ is free stream velocity. See detail Dobre et al. (2006)).

shows that the nominally two-dimensional wake develops a three-dimensional vortical structure composed of counter-rotating pairs of streamwise vortices. Similar vortex pair structures were also found by many others. In order to discriminate the primary instability i.e. spanwise vortices, the generation of streamwise vortical structures was named secondary instability. There are mainly two kinds of secondary instabilities existing in the circle cylinder wake, i.e. Modes A and B (Williamson, 1996a, 1996b; Wu et al., 1996). Both of the two kinds of instability appears as waves in the spanwise wake vortices, which evolve into pairs of counter-rotating streamwise vortices connecting the Karman vortices shown in Fig. 1. In Mode A, the sense of rotation of the streamwise vortices alternates once every half shedding cycle. Williamson (1996a, 1996b) attributed the formation of the Mode A to an elliptic instability, since the spanwise wavelength of its scales on the cores of spanwise vortex. While in Mode B, the streamwise vortices retain their sense of rotation over multiple shedding periods observed by Leweke and Williamson (1998). They observed the streamwise vortices of Mode B appeared in the braid regions, and argued that the mode B could lead to the instability of the hyperbolic regions (braid regions) of the flow. Unlike Modes A and B, an intermediate-wavelength mode called Mode S, a sub-harmonic mode (a complex Floquet multiplier with negative real part) with a period of twice the shedding period of the two-dimensional base state, is found in a square cylinder wake (Robichaux et al., 1999). Many researchers have studied the performance of the streamwise vortices. Wu et al. (1996) adopting PIV measurements pointed out that the streamwise vortices contain the maximum vorticity up to double that of the spanwise vortices, when fully developed. However, their net circulation measures just about one tenth of that of spanwise vortices. These secondary streamwise vortices cause the spanwise dislocation of Karman vortices and the energy transfer from the spanwise vortices to streamwise vortices with decrease of drag (Doddipatla et al., 2008). Therefore, it indicates that the streamwise vortices can reduce the drag and unsteady force of the bluff body.

In the present study, we focus on the 3D perturbations wake control and its mechanism of a bridge deck model with large aspect ratio. The elongated bluff body, comprised of an elliptical leading edge and a rectangular trailing edge, is relatively similar with bridge deck. Ryan et al. (2005) used Floquet instability to investigate the transition of the bluff body, and the results show that the dominant spanwise wavelength in the turbulent wake is likely to be much longer than that for a circular cylinder wake, and there are three unstable modes denoted as Mode A, B' and S'. For aspect ratios less than approximately 7.5, Mode A is the most unstable mode. For aspect ratios greater than this, the most unstable mode switches to Mode B'. This has the same spatio-temporal symmetry as Mode B for a circular cylinder, but a spanwise wavelength and near-wake features more in common with Mode S for a square cylinder. The dominant wavelength for this mode is approximately two cylinder thicknesses, much longer