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A study of wind effect on damping and frequency of a long span cable-stayed bridge from rational function approximation of self-excited forces*

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Wind effect on damping and modal frequency of long-span bridges can be investigated either in Laplace domain by using rational function approximation of self-excited forces (e.g. Chen, *et al.* 2000, Mishra, *et al.* 2007) or in frequency domain by directly using the Scanlan's expression of self-excited forces in terms of flutter derivatives (e.g. Ding, *et al.* 2002, Hua, *et al.* 2007). The latter approach seems more convenient and straightforward to obtain the results while having the additional expense of frequency iteration in solution course. Our main concerns in this discussion are the loci (or traces) of modal frequency and damping as a result of variation in wind velocity.

In reorganization that modal frequency and damping varies with wind velocity, some modes may interchange the original mode order with the increase of wind velocity (Ding, *et al.* 2002, Hua, *et al.* 2007). In other words, a mode may shift to a higher- or lower-order mode with increase of wind velocity. In such case, both the frequency and damping of the two modes should be interchanged to give a correct depiction of frequency and damping loci for a particular mode branch. As indicated in Fig. 5(b) of the paper by Mishra, *et al.*, modes 1, 2 and 3 interchange sequentially with increasing wind velocity. For example, the laterally-bending symmetrical mode (mode 1) is originally the first mode when the velocity is below somewhere between 20 m/s and 25 m/s (it is not clear to find out the exact value of wind velocity from Fig. 5(b)), and it becomes the second mode when the velocity is between 25 m/s and approximately 30 m/s. If the loci of frequency and damping for these interchanging three modes are plotted with original mode order as done in the discussed paper, the resulting loci is very fluctuating and actually depict incorrectly the variation of frequency and damping for a particular mode branch with wind velocity. Contrarily, the frequency and damping loci will be smooth rather than fluctuating and describe correctly the variation of frequency and damping with wind velocity if all the damping of a mode with the same modal characteristics is plotted for each locus (or line). In addition, whether the modes at different wind velocities originate from a same mode branch or not can be determined directly from mode shapes.

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The authors are thankful to the discussers for their interest in the contents of the paper and also for bringing to attention some of the works with a similar theme using different techniques. The discussers have rightly pointed out that the greatest strength of the technique applied by Chen, *et al.* (2000), Mishra, *et al.* (2007) is the avoidance of iterations in the solution process. Therefore, the method proves to be computationally efficient when structural and aerodynamic nonlinearities are to be incorporated as it avoids identification of a target mode at each step (for the purpose of mode branch computation) as needed in the frequency domain (mode-by-mode approach). The purpose of the study in the paper was to depict the variations in the frequency and damping of a natural structural mode due to varying mean wind velocity on a slender cable-stayed bridge deck.

Coming to the main concern of loci of the frequency and damping of the three interchanging modes 1, 2 and 3. To study the variation of frequency and damping of a natural mode with wind, the authors have gone through the extensive literature (e.g. Namini, *et al.* 1992, Dung, *et al.* 1998, Boonyapinyo, *et al.* 1999, Chen, *et al.* 2000a, b, Chen and Kareem 2003, Matsumoto, *et al.* 2001) and found similar (abrupt) variation especially for the potentially unstable modes in the vicinity of flutter critical speed. The unstable modes 1, 2 and 3 in the vicinity of 24 m/s (exact flutter speed is 23.4 m/s) show abrupt changes in their values. The authors would like to draw the attention of the discussers especially towards the paper by Namini, *et al.* (1992), Matsumoto, *et al.* (2001), Chen and Kareem (2003). These fluctuations are anticipated because of incorporation of structural and aerodynamic nonlinearities in the time domain analysis process. Nonetheless, the authors appreciate the discussers' careful scrutiny of the curves.

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