MODELLING OF VORTEX INDUCED VIBRATIONS OF SLENDER MARINE STRUCTURES

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Summary In this study vortex induced vibrations of slender structures in marine environment are considered. Two different approaches are adopted to analyse the complex fluid-structure interactions. First wake oscillator model is used to construct multi-modes approximations of the transversal oscillations of the straight flexible beam. Then computational fluid dynamics is used to verify the obtained predictions and to calibrate the wake oscillator model. Entrance to and exit from the lock-in conditions are examined in details.

INTRODUCTION

In this study we consider vortex induced vibrations (VIVs) of slender structures in marine environment. These structures such as risers, mooring cables, umbilicals and tethers are important elements of the subsea systems used in global offshore exploration, installation and production activities. As exploitation of offshore oil and gas fields is moving into deeper waters, the nonlinearities in the system and the fluid-solid interaction phenomena become more and more visible, and advanced modelling and analysis is required to describe and predict the behaviour of the system in general and vortex-induced vibrations in particular. The VIVs accelerate the fatigue damage of marine structures and limit the service life of overall subsea systems. So if this phenomenon is better understood and appropriately incorporated in the design process, substantial savings could be made by the industry.

MULTI-MODES APPROXIMATION OF TRANSVERSAL VIBRATIONS

This work is focused on the fluid-structure interactions of the straight flexible cylinder subjected to uniformed flow. First the approach used by Keber and Wiercigroch in [1, 2] is adopted and multi-modes approximation of the cylinder motion is obtained using the wake oscillator model [3]. The decomposition of the system's response into its modal components is achieved through substitution of the Galerking-type discretisation of transverse displacement and reduced lift coefficient using normal modes of the linear structure. One, two and three modes approximations have been constructed and they are used to investigate the lock-in phenomena when the frequency of vortex sheading synchronises with one of the structure natural frequencies. Influence of the system parameters on the dynamic response has been investigated and typical results are shown in Fig. 1. Figure 1a demonstrates the transversal amplitudes of the cylinder as function of the reduced velocity calculated at the different location along the cylinder. As expected, in the lock-in condition near second natural frequency of the cylinder in the middle of the structure ($z = 0.5$) the transversal amplitude is equal to zero which corresponds to the node of the linear structure. Figure 1b presents dependence of the transversal amplitude on the acceleration coupling coefficient A and as can be seen, there is a substantial variation in the predicted amplitudes as the values of A changes. So accurate determination of this empirical coefficient is very important for the accurate prediction of the vibrations amplitudes.

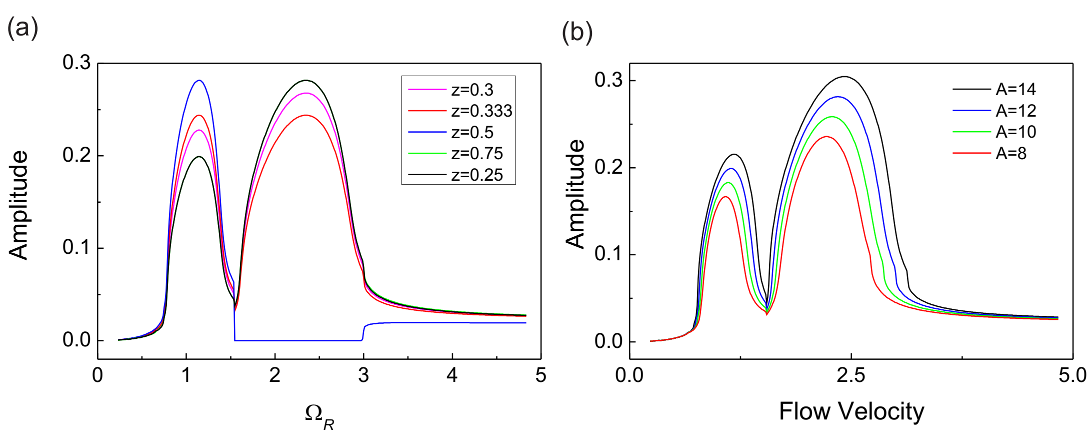

Figure 1. (a) Amplitude of the transversal vibration as function of the reduced velocity calculated at different locations along the cylinder using two mode approximation;(b) influence of the acceleration coupling coefficient A on the transversal vibration amplitude.

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To verify the predictions obtained using the wake oscillator model and to calibrate it, VIVs of a rigid cylinder in a two-dimensional flow has been studied using computation fluid dynamics (CFD) methods. A series of 2D CFD problems has been solved where the flow was analysed for the forced harmonic oscillations of the cylinder in transversal directions, then for the elastically supported cylinder capable of moving in transversal direction only and finally for the cylinder capable of moving in in-line and transversal directions. The forces acting on the cylinder have been calculated by integration of the wall pressure on the cylinder surface, and the drag and lift coefficients have been obtained as corresponding components of these forces. Transversal oscillations of the cylinder have been studied under varying system parameters including the velocity of the flow. Then the role of the in-line vibrations and their overall impact on transverse amplitudes at resonance have been investigated. The example of trajectory of the cylinder exhibiting both in-line and cross-flow oscillations is shown in Fig. 2 for the resonance case.

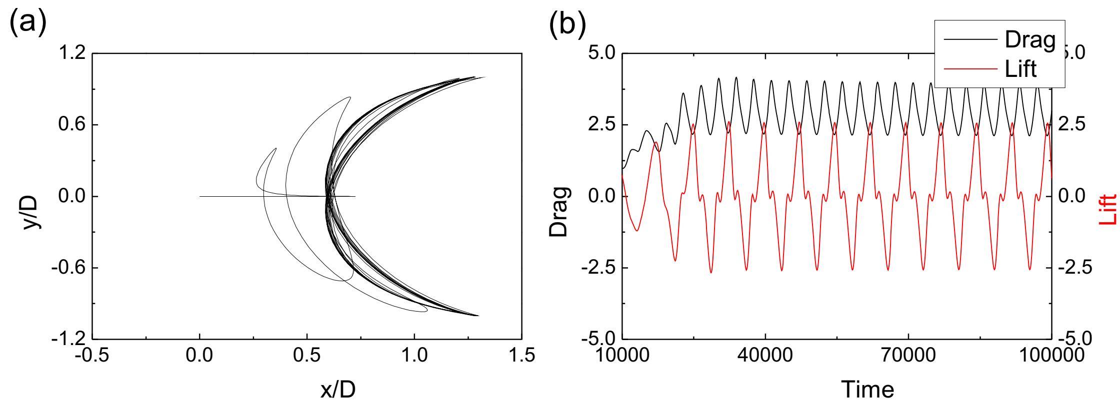

Figure 2. (a) The response of the cylinder in water at resonance (reduced velocity of 5) considering in-line and cross-flow oscillations, and (b) time history of lift and drag coefficients for m* = 1.275, Re = 1000.

Then the sub-critical regime, when the wake is fully turbulent, has been considered, and the system behaviour for a various mass ratios has been investigated, where particular attention has been paid to low-mass ratio cylinders. Simulations reveal that drag forces influence cross-flow amplitude, and it was found that their impact at resonance becomes more crucial as mass ratio of a cylinder decreases. The amplitude of the cylinder as a function of reduced velocity is presented in Fig. 3 for two values of the mass ratio. Simulations have been performed using dynamic mesh of quadrilateral structure, where the subsequent motion is determined based on the solution at the current time. The edges between mesh nodes are represented as network of interconnected springs.

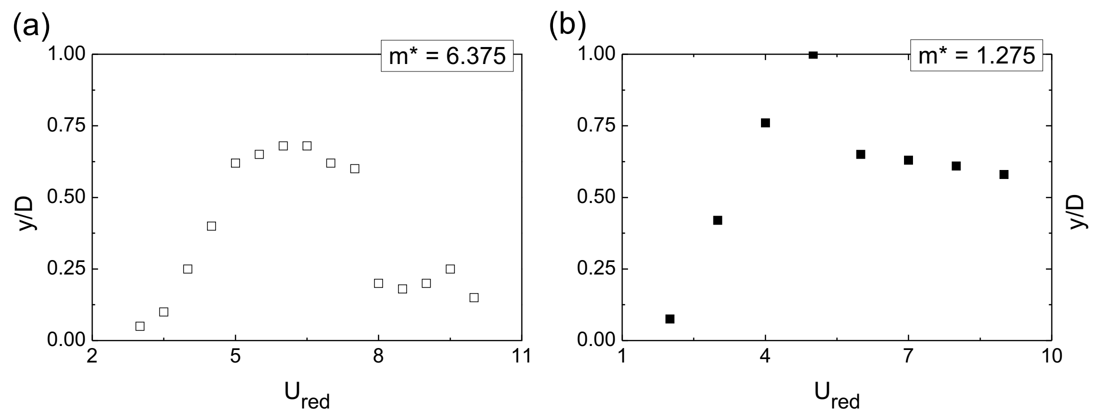

Figure 3. Transverse response as a function of reduced velocity at mass ratios equal to (a) 6.375 and (b) 1.275.

References

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