INVESTIGATION OF TRAVELING WAVE IN VORTEX-INDUCED VIBRATIONS OF LONG FLEXIBLE CYLINDERS

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Summary The respective contributions of traveling and standing vibration waves to overall vibration waves are investigated in this paper. Two methods are presented and expanded for the identification of traveling and standing vibration waves. One is a parametric method based on fitting an ellipse to the complex spatial amplitude distribution. The other is a non-parametric method based on the Hilbert transform. The parametric method was used to compute the ratio values between traveling and standing vibration waves in predicted displacement responses. An experiment was conducted to study the individual contributions of each type of vibration wave. Then the non-parametric method was used to separate the traveling and standing wave components in measured vortex-induced vibration (VIV) responses. It was found that the two methods worked very well and results show that the ratio value of traveling wave component increases with the velocity, indicating that traveling wave plays a more important role in VIV responses of long flexible structures in ocean engineering.

INTRODUCTION

Vortex-induced vibration (VIV) is a common phenomenon in many fields of engineering. The importance of VIV has led to a large number of studies summarized in the comprehensive reviews, e.g. Wu et al. (2011) [1]. However, most of these studies are focused on the VIV of short rigid cylinders, where the aspect ratio (the ratio of length to diameter) of the cylinders is usually smaller than 10^2. The features of VIV of long flexible cylinders have not been fully understood yet (Wu et al., 2010) [2], such as formation of traveling waves.

Traveling and standing vibration waves play important roles in VIV responses. For short rigid cylinders, which usually vibrate in low mode, standing wave behavior dominates the whole cylinders, whereas for long slender cylinders, both standing wave and traveling wave were observed in the field and laboratory experiments. When the traveling wave reaches both ends of cylinder, reflection generates a local standing wave-like pattern, which attenuates rapidly with the distance from the end. For very long cylinders, since the decay of wave reflected from both ends is so considerable that the standing wave induced by the reflection of wave is extremely weak, the responses are of traveling wave dominant pattern. However there is no study placed on assessing the individual influences of traveling and standing vibration waves on VIV responses independently.

The purpose of the present investigation is to evaluate the individual contribution of traveling and standing vibration waves to overall vibration waves. Two methods are presented and expanded for the identification of traveling and standing vibration waves. One is a parametric method based on fitting an ellipse to the complex spatial amplitude distribution. The other is a non-parametric method based on the Hilbert transform. The parametric method was used to compute the ratio values between traveling and standing vibration waves in predicted displacement responses. An experiment was conducted to study the respective contributions of each type of vibration wave. Then the non-parametric method was used to separate the traveling and standing wave components in measured VIV responses.

TRAVELING AND STANDING WAVES INDENTIFICATION

Fitting an ellipse to the complex amplitude in space

Consider a vibration wave progressing along the length of a structure. The vibration wave, having a single temporal frequency, ω, and a single wavelength in length, $\lambda = 2\pi/\kappa$, is formulated as the following.

$$u(x,t) = A(\kappa x)\cos\omega t + B(\kappa x)\sin(\omega t) + R(\beta x, \varepsilon t), \tag{1}$$

where $A(\kappa x)$, $B(\kappa x)$ are amplitude functions along the length and κ is the wave number, $R(\beta x, \varepsilon t)$ is a residual function characterized by a long wavelength β and a low frequency ε. It is shown that for a single wavelength, a plot of $A(\kappa x)$ versus $B(\kappa x)$ yield an ellipse. In the case of standing wave, the ellipse will converged into a straight line while pure traveling waves produce a perfect circle. The ratio of semi-minor to semi-major of the ellipse is used to scale the ratio of traveling wave component to overall vibration wave.

It is noted that this parametric method only considers single frequency and single wavelength case. Before fitting the ellipse, the multi-mode VIV response should be decomposed into several single mode responses by the modal analysis method.

Space localized separation by Hilbert transform

The Hilbert transform being a linear operator acts upon the sum of the individual wave components independently [3].

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The normalized composition of two wave components has the form of

$$u(x,t) = \cos(\kappa x)\cos(\omega t) \pm \gamma \sin(\kappa x)\sin(\omega t), \tag{2}$$

where γ is the portion of travelling wave in the composition. The composition has the Hilbert transform envelope and a phase shift respectively as

$$A = \gamma^2 \sin^2(\kappa x) + \cos^2(\kappa x), \tag{3}$$

$$\varphi = \arctan\left(\frac{\gamma \sin(\kappa x)}{\cos(kx)}\right), \tag{4}$$

By using the triangular factorization, the portion of travelling wave γ is found by

$$\gamma^2 = \frac{\sin^2(\varphi)}{A^{-2} - \cos^2(\varphi)} \tag{5}$$

The wave decomposition can be done with the identified portion of travelling wave γ.

INVESTIGATION OF INDIVIDUAL WAVE PORTION IN PREDICTED AND MEASURED RESPONSES

Identification of individual wave portions in predicted response

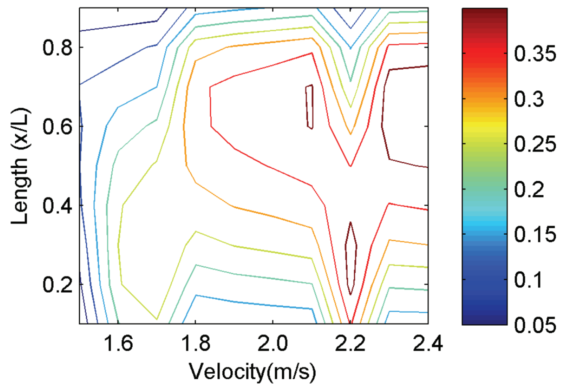

Fig. 1. The ratio value of traveling wave component to overall vibration wave

The method was used to identify the ratio value of traveling wave component to overall vibration wave in cross-flow VIV responses predicted by Ge et al. (2009) [4]. It appears from Fig.1 that the ratio value of traveling wave component increases with the velocity, and reaches the maximum at about 2.2m/s, then decreases slightly.

Identification of individual wave portion in measured response

The experiments were carried out in a towing tank. Space localized separation for measured cross-flow and in-line vibrations of a long flexible cylinder was evaluated by non-parametric method. The results show that the ratio value of traveling wave component increases with the velocity, and the non-parametric method separates the vibration wave into traveling and standing wave successfully. Due to the high speed flow, the travelling wave plays a more important role in VIV responses of long flexible structures in ocean engineering.

CONCLUSIONS

In this paper, the traveling wave and standing wave in vortex-induced vibrations of a long flexible cylinder are investigated by term of their individual contributions to overall vibration waves. Two wave identification methods were presented and expanded. It is shown that these two methods work very well and the results indicate that the ratio value of traveling wave component increases with the velocity.

Acknowledgements

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