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Experiments and modeling on the maximum displacement of a long tensioned mooring tether subjected to vortex-induced vibration

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Abstract

The maximum root mean square (RMS) of the displacement of a long tensioned mooring tether undergoing vortex-induced vibration (VIV) as the flow velocity varies was experimentally investigated, and an evaluation model was established to predict the maximum RMS value of the displacement by a dimensionless analysis. The results showed that the maximum RMS of the displacement linearly increased with the increasing of the flow velocity if only the low order modes were excited at the corresponding flow velocities. This kind of maximum RMS of displacement was evaluated by the proposed model, which is more reliable when it was used to predict the maximum RMS of the total displacement.

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Keywords: Long tensioned tether; vortex-induced vibration; displacement fluctuation; vibration mode; maximum displacement model

1. Introduction

Long tensioned mooring tethers are important components of engineering structures in deep oceans, such as deep sea platforms and submerged floating tunnels (SFT) [1], since they are designed to restrain the displacement and internal forces of the main bodies of deep ocean structures. Their safety has a close relation to the safety of the main bodies. One of the events that influence the safety of long tensioned mooring tethers is the vortex shedding of ocean currents passing through, which makes the tethers undergo vortex-induced vibration (VIV). Dynamic responses of the

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long tensioned tether subjected to VIV in recent investigations are stresses (strains) [2,3] and displacements induced in the process. For dynamic displacements, the focus was on the maximum root mean square (RMS) values, frequencies, dominant vibrations modes and wave types [4,5,6,7]. Wu et al.[8] summarized that the dynamic displacements of a long tensioned tether undergoing VIV were mainly characterized by multiple and high order modes, high harmonics and travelling waves in addition to standing waves. Dual resonance and non-resonance were studied as well [9]. However, the maximum RMS of the dynamic displacement of such tethers is not in-depth investigated.

In uniform flows, one concerned issue in VIV for a long tensioned tether with cylindrical shape is the effect of flow velocity on the maximum RMS of the displacement. Research results [6,9,10,11] showed that, as the uniform flow velocity increases, the maximum RMS of the displacement in both CF and IL directions increases in a saw tooth or fluctuating pattern. Such maximum value could be obtained by numerically solving the governing equations of the tether and the fluid field with the consideration of fluid-structure interaction [12,13]. However, it is a complicated and time-consuming work for the governing equations to be numerically solved. Therefore, a simpler and more direct evaluation model for the maximum RMS of the displacement of a long tensioned tether undergoing VIV is expected. In this paper, the maximum RMS of the displacement with the uniform flow velocity was first studied by an experiment. Then, according to the experimental results, a simple evaluation model was established to calculate the maximum RMS of the displacement of a long tensioned mooring tether undergoing VIV.

2. Experimental study

2.1. Experimental set-up and data Analysis

The experiment was carried out in a towing flume with the length of 29.0 m, the width of 4.5 m and the depth of 4.0 m [Fig. 1. (a)]. As shown in Fig. 1. (b), the test model was mounted on a towing car by universal joints. The state of uniform flows was attained by the towing car moving forward or backward along the length direction of the flume at a controllable constant speed. One end of the test model was connected with a cable and through pulleys the cable was hung with a steel weight inside a weight sleeve. By this set-up, the test model was tensioned.

An aluminum pipe with circular cross section was adopted as the experimental model, for which the length is 3.31 m, the outer diameter is 6 mm and the inner diameter is 4 mm. The axial tension had the value of 10 N. The uniform flow velocity varied from 0.1 m/s to 1.5 m/s with an increment of 0.1 m/s and numbered as 1 to 15 from 0.1 m/s successively. Table 1 summarizes the main parameters of the test model.

Fiber brag grating (FBG) strain sensors were stuck to the surface of the test model to measure the strains on the surface of the model. As illustrated in Fig. 1. (b), (c) and (d), 20 FBG sensors were installed at the CF direction and another 20 were at the IL direction with the sensor spacing of 160 mm. This arrangement implies that the test model is simplified as a 20-DOF damping system in each direction.

Table 1. Main parameters of test model

Experiment parameters	Symbol	Unit	Value
Length	l	m	3.31
Outer diameter	d_1	mm	6.0
Inner diameter	d_2	mm	4.0
Modulus of elasticity	E	GPa	71.0
Aspect ratio	l / d_1	-	551
Mass Ratio	m^*	-	1.5
Reynolds number	Re	-	600-9000