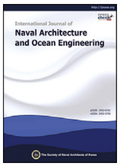
Available online at www.sciencedirect.com

ScienceDirect

Publishing Services by Elsevier

International Journal of Naval Architecture and Ocean Engineering xx (2016) 1—13

http://www.journals.elsevier.com/international-journal-of-naval-architecture-and-ocean-engineering/



Experimental study on vortex-induced motions of a semi-submersible with square columns and pontoons at different draft conditions and current incidences

Mingyue Liu [a,b], Longfei Xiao [a,b,*], Haining Lu [a,b], Xiaolong Xiao [a]

[a] *State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China*
[b] *Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai 200240, China*

Received 13 June 2016; revised 9 October 2016; accepted 13 November 2016
Available online ■ ■ ■

Abstract

The Vortex-induced Motions (VIM) phenomenon of semi-submersibles is relevant for the fatigue life of moorings and risers. Model tests regarding the VIM behavior of a semi-submersible with four square columns were conducted in order to investigate the effects of the current incidence and the aspect ratio of the immerged column. The experimental results show that the largest transverse amplitudes are around 70% of the column width at 30° and 45° incidences in a range of reduced velocities from 5 to 8 when the aspect ratio of the immerged column is 1.90. The largest yaw motion occurs at 0° incidence with the peak value around 4.5°. Similar characteristics of the VIM response are observed for the semi-submersible with aspect ratios of 1.90 and 1.73. When the aspect ratio decreases 50% to 0.87, 30% decrease in the peak transverse amplitudes can be seen.

Keywords: Vortex-induced motions; Semi-submersible; Current incidence; Aspect ratio; Model tests

1. Introduction

When a bluff body is exposed to a stream of fluid, alternating vortices can shed downstream from one side to the other of the structure, thereby creating an oscillatory hydrodynamic force. For a floating offshore platform, it moves laterally with a period under this oscillating force, which is called Vortex-induced Motion (VIM) in comparison with the Vortex-induced Vibration (VIV) observed for long slender structures such as risers. In general, the VIM behavior is characterized by large amplitudes in the same order of magnitude as that of the transverse section of the structure, and low frequencies close to the transverse natural frequency of the platform. Therefore, VIM causes significant drift in the horizontal plane which reflects on the mooring lines and risers regarding both extreme tension and fatigue life (see Huang et al., 2003; Cheng et al., 2011).

The offshore industry has recognized the importance of VIM phenomenon, and performed comprehensive evaluations of VIM for spar and mono-column platforms, as pointed out in van Dijk et al. (2003), Wang et al. (2009), Zhang et al. (2012, 2014) and Gonçalves et al. (2012a). For semi-submersibles, however, the investigation into VIM was reported more recently, as this phenomenon was only noticed with increasing draft dimension of the columns. The confirmed presence of VIM on the deep-draft semi-submersible (DDS) was found in field measurements by Rijken and Leverette (2009) and Ma et al. (2013). Rijken et al. (2011) and Rijken (2014) performed a series of tests to examine the influence of some

---

* Corresponding author. State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University, Shanghai 200240, China. Fax: +86 21 34207058.

E-mail address: xiaolf@sjtu.edu.cn (L. Xiao).

Peer review under responsibility of Society of Naval Architects of Korea.

http://dx.doi.org/10.1016/j.ijnaoe.2016.11.003

Please cite this article in press as: Liu, M., et al., Experimental study on vortex-induced motions of a semi-submersible with square columns and pontoons at different draft conditions and current incidences, International Journal of Naval Architecture and Ocean Engineering (2016), http://dx.doi.org/10.1016/j.ijnaoe.2016.11.003

aspects that are relevant on VIM of the DDS, such as the external damping, surface waves, appurtenances and column shapes.

Low aspect ratio is characteristic of floating platforms and has significant influence on the VIM phenomenon. Gonçalves et al. (2012b) carried out tests on cylinders with two degrees-of-freedom (DOF) at low aspect ratios and compared the results with high aspect ratio cylinders. The variations in the motion amplitudes and Strouhal number were observed due to the different aspect ratios. In the offshore scenario, Gonçalves et al. (2010) investigated the VIM phenomenon of a mono-column platform with different draft conditions, and indicated that lower aspect ratio (namely, *H/L*, where *H* is the immersed length of the column and *L* is the diameter or width of the column) decreased the VIM response. In regard to semi-submersibles, VIM is mainly excited by vortex shedding around columns. Thus, the dimension of the column, especially the immerged aspect ratio, is crucial in determining the VIM response of semi-submersibles. Waals et al. (2007) conducted model tests to examine the effects of the mass ratio, column height and different geometries on VIM behaviors of multi-column floaters (i.e. semi and TLP). The results showed that the immerged length of the column was influential for the magnitude of VIM response. This work also presented significant yaw amplitudes of multi-column platforms. In the same sense, Gonçalves et al. (2013) carried out model tests on VIM response of a semi-submersible at two draft conditions, and indicated that VIM behavior of the semi-submersible was highly influenced by the aspect ratio (*H/L*). Moreover, a seakeeping model test of a conceptual DDS was performed by Hong et al. (2008) to assess its global motion performance in wind, wave, and current environments. Although the test was not for the VIM of the DDS model, it can be clearly stated that a DDS with deeper draft will experience more significant VIM response with predictable oscillation period. Under this context and aiming to obtain more in-depth information on the influence of aspect ratio of the immerged column, VIM behaviors of a semi-submersible with four square columns were experimentally investigated under five draft conditions.

In addition, the incidence angle for square columns is important. Norberg (1993) pointed out that the Strouhal numbers of a square cylinder for 0° and 45° incidence angles were 0.13 and 0.17, respectively, and obtained different drag force coefficients. For a semi-submersible with multiple columns, the VIM phenomenon is more complex than that of cylindrical structures owing to the wake interaction of vortices shed from multiple columns. As a consequence of vortex shedding from each column, the wake interference is different for each current incidence. According to Gonçalves et al. (2012c), the largest transverse amplitudes were around 40% of the column width for 30° and 45° current incidences, and the largest yaw motions were verified for the 0° current incidence. In this study, VIM responses of a DDS at four different current incidences varying from 0° to 45° were discussed to determine the effect of current incidence.

2. Experimental program

2.1. DDS model

The experiments for a DDS model with a linear scale ratio of 1:64 were conducted in a towing tank with a length of 130.0 m, breadth of 6.0 m, and depth of 3.0 m. In towing tests, the platform moves together with the carriage in stationary water and the resulting flow conditions are nearly constant.

The DDS has four square columns with four rounded corners each, connected to four square pontoons with four rounded corners each. The model was a bare hull without any appendages. The main particulars are listed in Table 1, based on the dimensions defined in Fig. 1. *D* is the projected width of the column normal to the current and is defined as

$$D = L(|\sin\alpha| + |\cos\alpha|) \qquad (1)$$

where *L* is the column width and α is the current incidence angle. The projected width (*D*) tends to govern the width of the wake and is able to better represent the characteristic length of the column section subjected to the current.

In order to investigate the effect of aspect ratio of the immerged column on VIM response, five different draft conditions were considered at 45° incidence, as presented in Table 2. The mass ratio, which is greatly influential in the VIM behavior as reported by Waals et al. (2007) and Rijken (2014), is the same in all draft conditions.

2.2. Model test setup

In the experiment, the DDS model was restrained through an air bearing system and a horizontal mooring system connected to the towing carriage, as shown in Fig. 2.

In the air bearing system, the DDS model was equipped with four low-friction air bearings that slid along a smooth horizontal plate, which was supported by the towing carriage. The horizontal damping due to the friction of the air bearings was investigated by the decay test in the air, and was found to be less than 1% of the critical damping. Thus, the model was allowed to move freely in the horizontal plane, and vertical motions of the model were restrained. Moreover, the height of the horizontal plate can be adjusted to ensure that the draft of the model as well as the vertical pretension can be set as required.

Table 1
Principal dimensions of the deep-draft semi-submersible.

Parameter	Unit	Value	
		Prototype	Model
Column width (*L*)	m	19.5	0.305
Column corner radius (*Rc*)	m	3.0	0.047
Pontoon width (*Lp*)	m	19.5	0.305
Pontoon corner radius (*Rp*)	m	2.0	0.031
Pontoon height (*P*)	m	10.0	0.156
Draft ($H + P$)	m	47.0	0.734
Centre-to-centre column spacing (*S*)	m	72.5	1.133

Please cite this article in press as: Liu, M., et al., Experimental study on vortex-induced motions of a semi-submersible with square columns and pontoons at different draft conditions and current incidences, International Journal of Naval Architecture and Ocean Engineering (2016), http://dx.doi.org/10.1016/j.ijnaoe.2016.11.003