Ocean Engineering 148 (2018) 247–262

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Global dynamic response analysis of oil storage tank in finite water depth: Focusing on fender mooring system parameter design

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A R T I C L E I N F O

Keywords:
Dynamic response analysis
Floating storage tank
Mooring fender design
Sensitivity study

A B S T R A C T

A modular floating concept for oil storage is proposed. The concept is composed of several modular floating tanks and barges. The floating tanks are self-stable and designed for storage of oil and hydrocarbon material. The barges provide platforms for equipment and workers quarters, and enclose the floating tanks through mooring fender systems. The whole concept is then moored by mooring dolphins. This concept is designed for finite water depth application, however, potential application for deep water condition is also investigated. In this study, only single floating tank is investigated with both empty and full tank conditions considered. Different mooring fender configuration designs are the focus. It is assumed that the barges are fixed in the study of single tank dynamic properties, and multi-body hydrodynamic is neglected. Different regular wave conditions are used for the study of the dynamic performance of the tank under various fender mooring system parameters. Irregular wave together with wind and current for 100 year return period are also applied for the study of the tank dynamic performance. At last, sensitivity study of the viscous effects is performed.

1. Introduction

With the densification of populations in coastal cities, such as Singapore and Osaka, land becomes very scarce and expensive. The conventional approach of land reclamation is becoming time-consuming, environmentally unfriendly and expensive as the water depth gets larger. In these circumstances, very large floating structures (VLFSs) (Watanabe et al., 2004; Ohmatsu, 2005) are more suitable for offshore space exploitation. The advantages of VLFSs include low impact to the sea bed and environmental conditions and flexible deployment in terms of offshore positions. There are different types of VLFSs including floating bridges (Wan et al., 2017; Lwin, 2000), floating entertainment facilities, floating storage facilities, floating city, floating fish farm (Huguenin and Ansuini, 1978; Shainee et al., 2013), etc. Each application has its own scale and design principles, and the sizing of the floating structure and its mooring system depends on its function and also on the environmental conditions in terms of waves, current and wind.

In this study, a VLFS concept for storing crude oil or hydrocarbon in the sea is the focus. This concept is proposed for Singapore coastal waters with a potential application and deployment also in other coastal regions. Until now, there are only two floating fuel storage facilities in the world and both are located in Japan. One is Kamigoto Oil Storage Base and the other is Shirashima Oil Storage Base (Ueda, 2015), which are shown in Fig. 1a and b, respectively. The proposed floating storage facility consists of several modular floating tanks assembled together with barges that provide space for the associated equipment and workers quarters, which are shown in Fig. 1c. The operation facility modules to be implemented onto the barges are listed in Table 1. Each tank in this concept is moored by mooring fenders around its periphery. In this study, only one tank system with the surrounding mooring fenders is the focus. The treatment of the multi-tank system as well as tanks and barge system are outside the scope of this paper, but is only touched upon.

Fender system is broadly used in the ship berthing problems at a jetty. Fenders for large vessels can be categorized into three types (Eskenazi and Wang, 2015): rubber fenders, foam fenders and pneumatic fenders (Sakakibara and Kubo, 2007), and these are suitable for rigid berth, which can be applied to the system in this paper. Examples of these fender types are shown in Fig. 2 (Website, 2017). The fender can dissipate energy from ship or tank impact, and can also provide stiffness which affects the tank dynamic properties. Analysis principles of fender

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https://doi.org/10.1016/j.oceaneng.2017.11.021
Received 20 February 2017; Received in revised form 21 July 2017; Accepted 8 November 2017
Available online 22 November 2017
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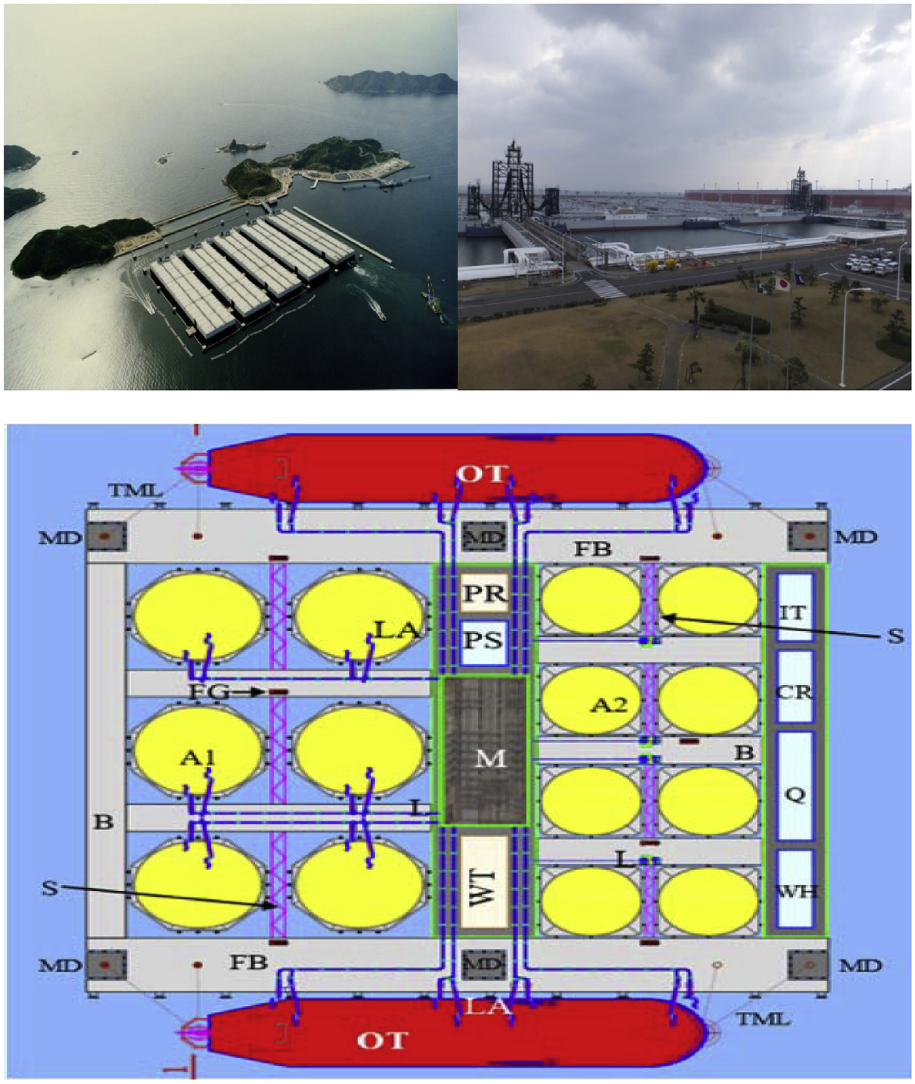

Fig. 1. (a) Kamigoto (upper left), (b) Shirashima oil storage bases (upper right) and (c) proposed floating oil storage facility (bottom).

Table 1
Facility on the oil storage platform.

Abbreviation	Facility
CR	Control Room
FB	Floating Berth
MD	Mooring Dolphin
Q	Workers' Quarter
TML	Tanker Mooring Line
PR	Pump Room
PS	Power Station
WH	Warehouse

system for ship berthing is addressed by PIANC in 2002 (PIANC, 2002). Fenders in contact with structures can induce friction forces when there are relative motions, roller type of fender system can attenuate the friction forces. In addition, fenders can also induce local stress due to relatively small contact area (Wan et al., 2016), and this should be taken into consideration from structural point of view. In this paper, the tank dynamic motions coupled with fender system is investigated assuming that fender system provides different stiffness parameters to the tank system. The detailed fender system configuration is not touched upon.

The oil storage tank is subjected to offshore wind, current and wave loads. The combined loads under offshore environment include both static and dynamic components. The static component such as mean wind, current and wave drift load will cause a static deviation or tilting of the tank location from its original equilibrium position; while the dynamic component excites wave frequency or low frequency dynamic response. The change of the incoming environmental load directions will also directly affect the fender reactions in a significant way. Since all the environmental loading will be resisted by the marine fenders installed on the barges, the appropriate design of the marine fenders become crucial for the safety of the system.

Frequency domain methods are widely used in the hydrodynamic responses of the coupled system for designing floating structures. However, in many applications such as floating wind turbine, floating wave energy converters etc., the viscous effect, transient loading events and nonlinear features may be important, and in these cases, a time domain model is more applicable (Wan et al., 2015). In the tank fender system, nonlinear features such as friction forces, tank-fender gaps, viscous effects from wind, wave and current are included, and nonlinear fender properties can also be considered. Hydrodynamic properties of the tank are firstly calculated in frequency domain, and then nonlinear features are included in time domain model. When there is liquid in the tank, free surface effects may also influence the tank dynamic motions under partially filled condition, an engineering approach of considering this free surface effect in time domain model is proposed in (Jin et al., 2017). However, it is not considered further in this study.

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