Marine Structures 63 (2019) 153–180

Contents lists available at ScienceDirect

Marine Structures

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

Experimental modelling of mooring systems for floating marine energy concepts

Carlos Barrera*, Raúl Guanche, Iñigo J. Losada

Environmental Hydraulics Institute, Universidad de Cantabria, Avda. Isabel Torres, 15, Parque Científico y Tecnológico de Cantabria, 39011, Santander, Spain

ARTICLE INFO

Keywords:
Flume
Experiment
Mooring lines
Dynamic
Acceleration

ABSTRACT

New floating devices are emerging thanks to a highly active marine renewable energy sector. These concepts, featuring floating offshore wind installations as well as other projects in the wave energy sector require innovative mooring systems. Therefore, a complete analysis of this element is required to achieve a successful design.

This paper investigates the behaviour of mooring systems based on catenary configuration thanks to a detailed experimental program. Tests to characterize the properties of the mooring lines, and geotechnical and hydrodynamic trials were also performed on a 1:40 laboratory scale. Mooring truncation problem is normally faced by the researchers working on model testing of mooring lines in deep water, because the depth of the lab is typically small. However, it does not seem to be a problem for offshore floating renewable energy devices which are usually in relatively shallow water. The influence of catenary weight, imposed displacements at the fairlead, wave-current loads and different types of sea bottom friction on the mooring systems were analysed in terms of tensions, movements and shape of force-displacement curve. However, scaling of the sea bottom and the mooring line interaction is a challenge. Although the damping effect was investigated and compared under different movement conditions, the conclusions achieved can be upscale to real scale but it must be noticed that there are limitations due to scale effect issues. A total of 111 test were performed. The influence of the hydrodynamic inertia and drag is negligible on long wave and slow motions, while they have more importance during shorter waves and quick motions. The results reveal the importance of acceleration in the movement being possible to distinguish dynamic and quasi-static performance depending on the acceleration of the mooring line.

1. Introduction

Deep water areas represent the future of renewable marine developments due to the presence of greater and better wind and wave energy resources, among numerous other reasons [1]. Because of this, the number of floating marine energy concepts has increased in recent years with new prototypes of wind floating platforms [2], multi-use platforms [3] and wave energy converters [4]. These floating structures are generally secured by mooring systems. The main function of a mooring system is to restrict the low frequency motions of the floating structure and to resist environmental actions.

Mooring systems are constituted by one or several lines anchored to the seabed which are connected to a floating platform at a

* Corresponding author.
E-mail address: barrerac@unican.es (C. Barrera).

https://doi.org/10.1016/j.marstruc.2018.08.003
Received 23 October 2017; Received in revised form 15 May 2018; Accepted 10 August 2018
0951-8339/

point called a fairlead. Essentially, four different types of configurations can be found: catenary, semi-taut, taut and tether. Most of them are comprised of steel chain links and steel wires. However, synthetic fiber ropes are widely used in semi-taut and taut mooring systems.

The catenary configuration is one of the most common. A catenary is the curve that a hanging chain, cable or rope shows under its own weight when it is supported only at its ends. Catenary systems always have enough line length resting on the seabed to avoid vertical forces on the anchoring system. Catenaries are typically moored with drag embedded anchors. This configuration does not allow vertical loads so a sufficiently long line length resting on the seabed is required to avoid them.

Mooring systems are an essential part of floating structures to ensure their survivability and stability. Moreover, they constitute an important element in the cost breakdown, typically about 8% of the capital expenditure of a typical marine platform installation [5], and therefore they have a large impact on the cost of energy.

Mooring integrity management for marine renewable energy concepts takes the fundamentals and the advances made by the oil and gas industry. An evaluation of alternatives for offshore petroleum production system in terms of type of platforms, moorings and riser system is made by Morooka et al. [6]. He generated a database formed by all offshore petroleum production systems and he concluded that four types of platforms are able to be used in deep and ultra deep water: Floating Production System and Offloading units (FPSO), Semisubmersible platforms, Spar and Tension Leg Platforms (TLP).

The main failure modes that affect the dynamics of a mooring system are exposed by Gordon et al. [7]. He developed a comprehensive review of the current state of the art in mooring integrity management. He suggested that some progress are required to low the average failure rate in moorings. Some of them are related to better wear and corrosion degradations models, a better understanding of out of plane bending induced fatigue, S-N data for higher strength chain grades and more reliable inspection and monitoring tools.

The effect of mooring system on the dynamic response of floating platforms has been discussed by different researchers. Agarwal et al. [8] studied the effects of initial horizontal force at the top of mooring line, the coupling of stiffness matrix, the structural damping and the drag coefficient on the response of spar platforms. Some conclusions of his work reveal the importance of the force-excursion curve on the natural periods and the dynamic response. Variations of the initial horizontal force at the top of the mooring line affect surge and heave responses significantly. The coupling of stiffness matrix has an important role in the dynamic behaviour of offshore platforms, above all, in heave response. Structural damping ratio does not have effect on surge and pitch responses but it is important on heave response. Surge, heave and pitch responses proportionately vary with the value of inertia coefficient being the influence of drag coefficient appreciable in surge response.

Liu et al. [9] modelled the behaviour of Ultra Large Floating Structure (ULFE) for exploitation of resources and construction of sea-islands using a combination of physical and numerical models. His laboratory tests required a truncated mooring system. He concluded significant improvements in the hydrodynamic behaviour of ULFE can be achieved in the design of wave chamber and breakwater.

Srivastava et al. [10] discussed the dynamics of submerged buoy for disconnection at drilling vessels and production platforms conducting oil and gas operations for station keeping in drifting pack ice. A safe disconnection system is needed as ice loads can exceed the capacity of the mooring system used for station keeping. His results showed high dynamic forces between the buoy and the vessel and a significant upward buoy motion after its initial drop at high vessel offsets. This phenomenon can generate a local compression at the top of the risers. Design should avoid local buckling of the riser top. He concluded a sensitivity analysis should be made to possible variations of parameters such as contact stiffness, added mass and damping coefficients for the design of disconnectable buoy mooring system.

Chen et al. [11] studied the response of a spar constrained by slack mooring lines to steep ocean waves using a quasi-static and dynamic approach comparing the dynamic coupling effects in different water depths and analysing the effects of mooring damping on the spar movements. His conclusions reveal the importance of mooring damping for reducing the slow-drift surge and pitch of the spar. This reduction increases with the water depth.

Experimental studies of mooring line dynamics have been carried out by several researchers. Lindahl [12] investigated the behaviour of the pitch of a mooring line using a chain which was excited by vertical circular motions with various radii and periodicities, measuring the force in the upper end of the chain. Simos et al. [13] continued analysing pitch behaviour, adding current effects to the mooring line dynamics using a compound line (chain and wire rope). They included different combinations of the amplitude and the frequency of motion in order to generate a set of experimental results of the dynamic tension acting on the top of a mooring line model with circular harmonic motions imposed at its top. Azcona et al. [14] studied surge behaviour on mooring lines. A mooring line was excited with prescribed motions producing different dynamic conditions, including harmonic response, loss of tension, and snap loading, focusing on the shape of the line and the tension at the fairlead. Gobat et al. [15] analysed the dynamics of catenary moorings in the region surrounding the touchdown point by means of experiments and numerical simulations. He discussed the shock forms in the tension with bottom interaction. He concluded shoks during upward motion of the mooring are manifested as snap load in the tension and during downward motion appear as slack tension.

Taking into account all the previous research, there are still some knowledge gaps that need to be addressed, for example: the influence of weight, the sea bottom friction, the natural loads (waves, currents and wave-current) and the prescribed movements at the fairlead position on mooring lines.

The aim of this paper is to experimentally analyse the dynamic behaviour of different mooring lines and the impact of weight and sea bottom friction, and the importance of acceleration on the catenary considering different fairlead movements not yet analysed in the literature.

The paper is organized as follows. Section 2 provides an overview of the experimental test campaign, detailing the test facility, the