Ocean Engineering 83 (2014) 76–86

Contents lists available at ScienceDirect

Ocean Engineering

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

Hydrodynamic loads and response of a Mid Water Arch structure

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ARTICLE INFO

Article history:
Received 27 February 2013
Accepted 22 February 2014
Available online 12 April 2014

Keywords:
Mid-Water Arch
Hydrodynamic Loads
Experimental
Numerical Analysis

ABSTRACT

A Mid Water Arch (MWA) is a subsea structure used in flexible riser and umbilical systems. Understanding the hydrodynamic properties and response of the MWA to environmental conditions is important in the design of such systems. In this study, these areas have been investigated through both experimental model scale testing and numerical simulations. To carry out the model scale testing it was necessary to develop two experimental methods; captured testing to determine the drag forces on the structure, and tethered testing to enable the offsets, rotations and tether tension loads to be resolved. The numerical simulations are comprised of Computational Fluid Dynamics (CFD) with ANSYS CFX to explore the drag forces on the MWA, hydrodynamic diffraction analyses with ANSYS AQWA to find the added mass of the MWA, and dynamic analyses with OrcaFlex to study the offsets and rotations of the MWA in the tethered arrangement. The model testing results were used for comparison and validation of the numerical simulations; namely, the captured testing and CFD studies, and the tethered testing and OrcaFlex analyses. The findings from this study have shown the significance of experimental testing for the purpose of investigating the hydrodynamic loads on a MWA structure.

1. Introduction

A MWA is a buoyant subsea structure that is tethered to the seabed and suspended usually mid-way through the water column. They are used in flexible riser and umbilical system to achieve a lazy-S or steep-S riser configuration, both of which are commonly used in conjunction with Floating Production Storage and Offloading (FPSO) facilities (Russell and Vignaud, 2011). The purpose of the MWA is to protect the integrity of flexible risers and umbilicals by supporting them in the mid-span vicinity. In doing so the cumulative riser tension is reduced; vessel and wave motions can be accommodated; the allowable riser curvature is maintained; clashing or entanglement of risers is avoided; and the touch-down point remains constant.

A range of designs exist for MWA structures, all of which have the following components: a buoyancy tank or module that supports both the weight of the structure and associated riser(s), gutters or guides that control the position and bending radius of the riser, clamps to secure the risers within the respective gutters and a tether and bridle arrangement fixed to a seabed foundation for positioning of the structure.

Numerical analysis software is commonly used in the design and analysis of riser systems to understand the motion response of the MWA in varying environmental conditions. OrcaFlex is one such programme; three-dimensional bodies, such as the MWA, are modelled as a lumped 6D-buoy. The 6D-buoy is a mass that experiences six degrees of freedom and it requires a range of inputs, including the hydrodynamic coefficients and principal dimensions. Subsequently the loads and motion response of the structure are calculated from Morison's equation (Orcina, 2010).

While structural attributes of the MWA are defined, hydrodynamic coefficients are not readily available for complex structures and data is only given for simple shapes, such as cylinders, cubes and spheres (DNV, 2010). Literature discussing the hydrodynamic properties and response of complex structures, such as the MWA, is somewhat limited. Koolhof et al. (2012) and Russell and Vignaud (2011) numerically determined hydrodynamic coefficients for particular MWA designs, and their studies showed limitations of computational simulations in application to MWAs due to shape complexity. This leads to the requirement of model testing, since it provides another method of determining the hydrodynamic loads and motion responses for the MWA, with fewer simplifications or assumptions, and it can be used to validate results from numerical simulations. Full scale testing is

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Abbreviations: CAD, Computer Aided Drafting; CFD, Computational Fluid Dynamics; DAQ, Data Acquisition; DNV, Det Norske Veritas; FPSO, Floating Production Storage and Offloading; SST, Shear Stress Transport; MWA, Mid-Water Arch

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http://dx.doi.org/10.1016/j.oceaneng.2014.02.032
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normally impractical, since it is not cost effective, or possible in most situations. Furthermore, a controlled testing environmental is essential for obtaining results that are accurate and repeatable.

In this paper, the drag forces and motion response of a scale MWA model were investigated both numerically and experimentally. Numerical simulations have been conducted using ANSYS CFX and AQWA to obtain comparative hydrodynamic coefficients, and OrcaFlex was employed to investigate the MWA motion response.

2. Model experimentation

The experiments were carried out in the Australian Maritime College flume tank in Beauty Point, Tasmania, Australia. The flume tank testing area is 11 m long, 5 m wide and 2.5 m deep. The tank is capable of generating maximum flow speeds of 1.5 m/s.

The MWA design has been provided courtesy of Technip, it comprises of a single buoyancy tank and 4 gutters, each used to accommodate a single riser for transporting hydrocarbons to the topside facility. Experimental data was measured using a body fixed coordinate system to replicate the typical full scale MWA arrangement. The flow parallel to the X-axis was defined as 0° and flow parallel to the Y-axis was 90°. Fig. 1 shows the scale model tethered MWA arrangement, the coordinate system and flow directions referred to in the paper are presented.

The MWA model was constructed at a 1:15 scale; this enabled a sufficient model size to achieve accurate geometric similarity, while still being small enough to be tested in the Circulating Water Channel Facility. The model was 1160 mm in length, 720 mm in width and 490 mm in height. The model mass was 18.55 kg and an additional 17.30 kg of ballast was added. The model arch was made from aluminium sheet metal that was tack welded around a curved internal frame. This framework was made of aluminium plate and tube, which was welded to the external aluminium stiffeners. External stiffeners were connected to the buoyancy tank with epoxy resin. The buoyancy tank was made from a combination of fibreglass, epoxy resin and PVC pipe, where the elliptical ends housed PVC threaded caps to allow easy access for ballasting. The gutters were bolted to the aluminium arch through a series of welded brackets with tapped threads and this allowed them to be moved or altered for testing variations. The gutter guides were made from moulded epoxy and they were nailed onto the upper edge of the gutters.

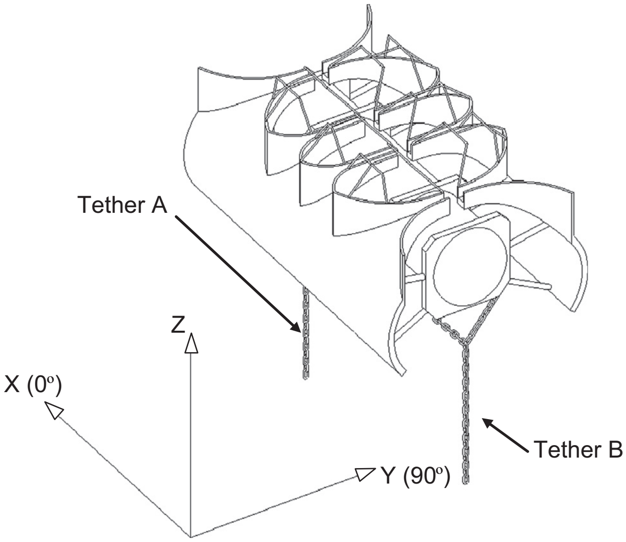

Fig. 1. The MWA model configuration and coordinate system.

The Reynolds numbers, Re, can be defined by the flow speed, V, the MWA length, L, and the kinematic fluid velocity, υ, as

$$Re = \frac{VL}{\upsilon} \quad (1)$$

The Reynolds numbers encountered in MWA applications are generally around the magnitude of 1×10^7 due to the structure size. Due to limitations for the maximum speed in the testing facility, it is not possible to use Reynolds scaling since the required flow speeds exceed the operating capabilities of the testing facility. This occurrence is commonly encountered when testing large subsea structures and it is resolved by using Froude scaling (Jacobsen and Leira, 2012). The Froude number, Fn, can be given in terms of the flow speed, V, gravitational acceleration, g, and MWA length, L, as

$$Fn = \frac{V}{\sqrt{gL}} \quad (2)$$

The difference in Reynolds number between model and full scale may result in drag force not being scaled. In particular, smaller Reynolds numbers at model scale may exhibit a laminar flow regime which is different to what occurs at full scale and therefore viscous forces not scaled correctly. However, the drag on the MWA is pressure dominated due to its shape and size, a trait typically exhibited by bluff bodies (White, 2002); and the flow separation caused by the sharp edges and appendages of the structure were expected to be considerably larger than the separation within the boundary layer.

2.1. Captured test arrangement

The captured experimentation was conducted to determine the translational drag on the MWA model (Fig. 2). The drag forces and moments were measured using a 250 lb capacity AMTI MC3A force/torque sensor (load cell). The waterproof load cell measured three orthogonal forces and moment components along the X, Y and Z axes with a tolerance of ±0.2% for non-linearity and hysteresis. A multi-channel data acquisition (DAQ) system was used to collect the data, where it was recorded and analysed using LabVIEW software. The load cell was mounted between the top of the MWA and a vertical rod attached to a metal support frame. The support frame utilised two linear bearings to ensure the rod apparatus remained vertical while changing the model orientation. A gauge plate attached to the upper

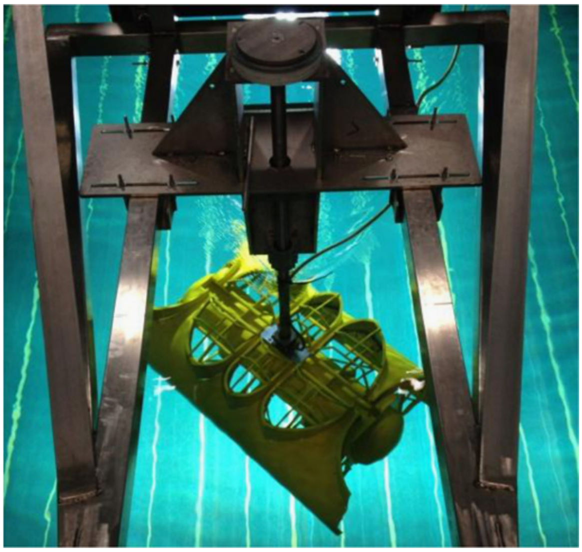

Fig. 2. Captured testing of the model MWA setup (orientated at 45°).