Ocean Engineering 82 (2014) 180–190

Contents lists available at ScienceDirect

Ocean Engineering

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

Forces on a cruciform/sphere structure in uniform current

Pål Lader [a,*], Birger Enerhaug [a], Arne Fredheim [a], Pascal Klebert [a], Bjørnar Pettersen [b]

[a] SINTEF Fisheries and Aquaculture, N-7465 Trondheim, Norway
[b] Department of Marine Technology, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

ARTICLE INFO

Article history:
Received 21 June 2013
Accepted 3 March 2014
Available online 25 March 2014

Keywords:
Hydrodynamics
Drag force
Net structure

ABSTRACT

Experiments have been conducted on a cruciform structure in uniform flow. The cruciform consists of two intersecting cylinders and a center sphere and is assumed to mimick two twines (cylinders) that meet in a knot (sphere). The experiments are motivated by the need for a better understanding of drag forces acting on net based structures such as fish farms. The cruciform model was designed so that is it was possible to isolate the forces acting on the separate cylinders from the forces acting on the sphere only. It was found that the cylinders in the cruciform experienced a drag coefficient similar to established measurements of a cylinder in uniform flow ($Cd \approx 1.0$). The sphere, however, experienced a drag coefficient that was between two and three times higher (Cd in the area 1.1 to 1.6) that what previously have been found for a single sphere in uniform flow ($Cd \approx 0.5$).

1. Introduction

Flexible structures in general, and thus most aquaculture structures used today, have a behaviour that is more complex than the behaviour of rigid body structures, e.g. ships or semi-submersible offshore platforms. A flexible structure is inherently more compliant to large loads than a rigid body structure, as the flexibility allows the structure to deform, and consequently reduce both local stresses and global loads. The wave/current compliance of a flexible structure is highly dependent on the design. It is important to have a good understanding of the behaviour of such a flexible structure in different sea load scenarios when the flexible characteristics of the structure is decided (Gosselin and de Langre, 2011).

Numerical models are important design tools that can predict the behaviour of these net based structures in specific sea conditions, how they move and deform, magnitude of structural stresses and global current and wave loads. Such models have been proposed by several authors, and there are different possible approaches. One way is to model the net as individual knots and twines, calculating the total drag on the net as a sum of the drag of the individual elements (Fredheim and Faltinsen, 2001) and applying a structural analysis based on truss elements (Theret, 1994). This approach makes it possible to account for details in the net structure and to study the flow inside and around the net structure. One variation of this approach is to model the net as knots and twines, but to use a larger bar length and twine diameter to decrease the number of elements used in the analysis. The hydrodynamic and structural properties of the elements in the model are found by requiring the model elements to be consistent with the original net. This method is used in the AQUA-FE model described by Tsukrov et al. (2003) and Moe et al. (2010). A different approach is to model the net by dividing it into super elements, where each element has properties that simulate the twine and knot structure of the netting (Lader et al., 2003; Endresen et al., 2013; Kristiansen and Faltinsen, 2012).

For all of these methods it is important to have an accurate method to estimate the hydrodynamic load on the model. The hydrodynamic load model is the core of the method, and the accuracy of the method itself is not better than the accuracy of the hydrodynamic load model. Some of the methods, like (Lader et al., 2003), use empirically based formulas for the hydrodynamic loads (Aarsnes et al., 1990 and Løland, 1991), others use a CFD (Computational Fluid Dynamics) approach (Vincent and Marichal, 1997). The most straight forward way to estimate the drag forces on a net structure is however to assume that the twines and knots of a net is similar to cylinders and spheres, and then calculate the forces on each cylinder and sphere element and sum them together to get the load of the whole net. Fredheim (2005) studied this method to calculate forces and found that, particularly for nets with high solidity ratio the forces calculated using the cylinder/sphere approach under-predicted the force compared to laboratory measurements. Fredheim concluded that the drag forces on a net cannot be treated only as a sum of the drag forces on the individual elements when the solidity ratio increases above a certain value. Fredheim also states that this non uniform relation between the drag force and the solidity has been noted, but not explained, by several authors (for instance (Koritzky, 1974 and Fridman and Carrothers, 1988)). Fredheim suggests that this discrepancy is due to flow interaction

* Corresponding author. Tel.: +47 92 68 07 05; fax: +47 93 27 07 01.
E-mail addresses: Pal.Lader@sintef.no, pal.lader@gmail.com (P. Lader).

http://dx.doi.org/10.1016/j.oceaneng.2014.03.007
0029-8018/

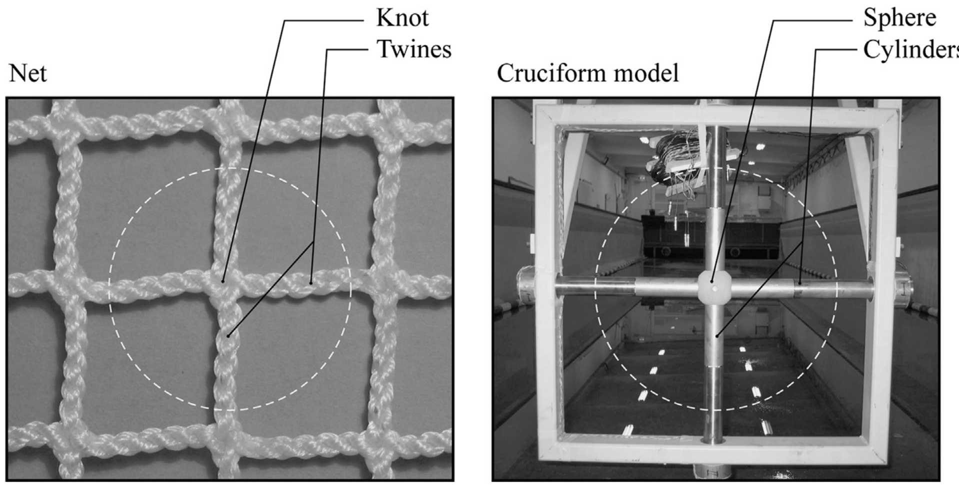

Fig. 1. The principle and motivation between the experiments: The cylinder/sphere configuration (cruciform) is supposed to simulate a twine/knot area in a real net.

between the different parts of the net around the knot part, although this mechanism is not well understood at all.

In the present work we have studied the contribution of the knots on the total force on a net structure by isolating and measuring the individual forces on the twines and the knot. In order to do this, an idealized model of a twine/knot crossing was constructed by two crossing cylinders, a cruciform, with an additional centre sphere (see Fig. 1). The model was constructed so that it was possible to measure the forces on the individual cylinders and the sphere.

2. Methods

2.1. The cruciform model

As described in the introduction, the model consisted of a vertical and a horizontal cylinder that intersected in a sphere as shown in Fig. 1. This geometry is called a cruciform. In order to measure the forces on the four cylinders in the cruciform individually, the model was equipped with four proprietary load cells, one in each of the four cylinders (upper, lower, port side and starboard side cylinder), as shown in Fig. 2. The load cells used strain gauge technology and measured the forces along the *x*-, *y*- and *z*-axis on each cylinder. Each measurement cylinder (the white cylinders in Fig. 2a and b) was mounted as a cantilever arm connected to another cylinder (the grey cylinders in Fig. 2a and b) that is fixed to the outer frame. Each cantilever cylinder consists of a load cell fixed to a brass rod, both covered with a brass tube (Fig. 2d). The fit surface between rod and outer cylinder is very tight. Since the stiffness of a load cell is in inverse ratio with its sensitivity and resolution, a certain amount of deflection had to be accepted in order to get the desired accuracy in the measurements. Consequently, all cylinders were mounted with a small gap of approximately 2 mm between the cantilever base and the fixed cylinder. The centre square of the cruciform (the intersection between the cylinders) is part of the upper cylinder. Between the centre square and each of the three other cylinders there is a gap of approximately 2 mm in order to assure that all four cylinders are independent and do not get in contact with each other. It is important that the forces measured by the load cells are exclusively the hydrodynamic forces acting on each individual cylinder, and no forces should be mechanically transferred from some of the other cylinders. The gap is considered to be so small that it does not significantly disturb the flow. When the centre sphere is connected to the cruciform (configuration 2, 3 and 4 in Fig. 3), the sphere is fastened to the top cylinder only. The sphere has holes for the other three cylinders with a gap of approximately 2 mm in order to keep all four cylinders mechanically independent. The force on the sphere itself can thus be isolated by taking the force on the upper cylinder and subtracting an estimate of the force acting on the cylinder part. The force on the cylinder part can be assumed to be similar to the force measured on one of the other cylinders. Thus the model is constructed so that it is possible to isolate the forces acting on each individual part, all the four cylinders and the centre sphere.

Unfortunately, due to technical problems with the force sensor in the starboard cylinder these measurements were lost. The measurements on the port cylinder showed large discrepancies that could not be explained otherwise than that is was due to measurements error, and the port cylinder measurements was discarded. Thus only the measurements on the upper and lower cylinder could be used, and it was assumed that the force on the upper cylinder part was similar to the force on the lower cylinder, and that the force on the sphere could be estimated by subtracting the force on the lower from the force measured in the upper cylinder.

Five different configurations of the model were used in the experiments (Fig. 3): Cruciform only (1), cruciform with 10, 15 and 20 cm sphere (2, 3 and 4), and finally a vertical cylinder (5). The vertical cylinder was used as a test case to assess the validity of the force measurements, since forces on cylinders in uniform flow is well known in the literature. It was also used to verify that the force on the upper part and the lower part of the cylinder was similar.

2.2. Laboratory setup

The cruciform model was subjected to uniform current of different velocities. In the planning phase of the experiments it was considered to either use a flume tank or a circulation tank. A circulation tank have the obvious advantage that it is possible to run as long time series as possible, but it has the clear disadvantage that there will always be an uncertainty of the in-flow condition. It is impossible to construct perfect uniform parallel flow in a circulation tank, there will always be residue turbulence generated in the device that sets up the current (i.e. impellers, pumps). Honeycombs etc. can be used to remove most of the turbulence and other unwanted flow structures, but it is impossible to be sure that everything is removed and there will always be an uncertainty regarding the quality of the flow.

It was of paramount importance to have control of the inflow conditions since small disturbances in the inflow could influence