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Numerical benchmark studies on drag and lift coefficients of a marine riser at high Reynolds numbers

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ABSTRACT

Numerical benchmark studies on drag and lift coefficients of a marine riser have been organized by the 27th ITTC Ocean Engineering Committee. The purpose of the studies was to benchmark the capabilities of CFD methods through quantitative comparisons and validation studies against the model test results of a circular cylinder by MARIN. Studies were focused on the drag crisis phenomenon for the stationary smooth cylinder in the critical Reynolds number regime. Eight organizations have participated in the studies by using RANS, DES and LES methods. An overview of the model test results, test cases, submissions and comparison results are presented in this paper. Conclusions and recommendations are made for future studies.

1. Introduction

Vortex Induced Vibration (VIV) of marine risers poses a significant challenge as the offshore oil and gas industry moves into deep water. Due to the asymmetric nature of the vortex shedding, risers vibrate in both in-line and cross-flow directions. The in-line motion can be a major contributor to the fatigue damage due to its higher frequencies and response modes although the in-line displacement is normally less than the cross-flow one. It also triggers higher-order harmonic responses in both in-line and cross-flow directions which further increase the fatigue damage.

Marine risers have very large length-to-diameter ratios, especially for deepwater risers. The length of risers cannot be scaled due to the depth limitation of existing wave basins and therefore experimental methods cannot be reliably employed for design verification. To predict the VIV response of a riser system, practical numerical methods have been developed by making use of databases with experimental hydrodynamic coefficients at various Reynolds numbers, for example, those by Oakley and Spencer [1]. Most experiments have been carried out to measure the hydrodynamic forces on a segment of a riser. The experimental databases, however, cover a limited range of Reynolds numbers for a segment of rigid or flexible riser. It is desirable to use computational fluid dynamics (CFD) methods to compute the hydrodynamic forces on marine risers, complementing the experimental databases for VIV prediction, and to simulate the responses of long risers.

CFD simulations of VIV have been focused on flow around circular cylinders and their induced forces. While the cylinder geometry is simple, it remains challenging for CFD methods to resolve the flow instability and separation in the boundary layer and in the wake. Since 2009, the ITTC Ocean Engineering Committee has carried out studies to benchmark the capabilities of CFD methods for the prediction of hydrodynamic forces on a stationary smooth cylinder at high Reynolds numbers. In the benchmark studies organized by the 26th ITTC Ocean Engineering Committee, all participants used the two-dimensional unsteady Reynolds Averaged Navier-Stokes (URANS) method. Various turbulence models were employed with the assumption that the flow is fully tur-

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Nomenclature

Abbreviations

AR	Aspect ratio of the cylinder, L/D
C_D	Drag coefficient, $F_D/(\frac{1}{2}\rho U^2 DL)$
C_L	Lift coefficient, $F_L/(\frac{1}{2}\rho U^2 DL)$
D	Cylinder diameter
F_L	Lift
F_D	Drag
f_s	Shedding frequency
L	Length of the cylinder
Re	Reynolds number, UD/ν
St	Strouhal number, $f_s D/U$
U	Inflow velocity
ρ	Density of water
ν	Kinematic viscosity
ITTC	International towing tank conference
CFD	Computational fluid dynamics
DES	Detached eddy simulation
LES	Large eddy simulation
URANS	Unsteady Reynolds averaged Navier-Stokes equations
VIV	Vortex induced vibration

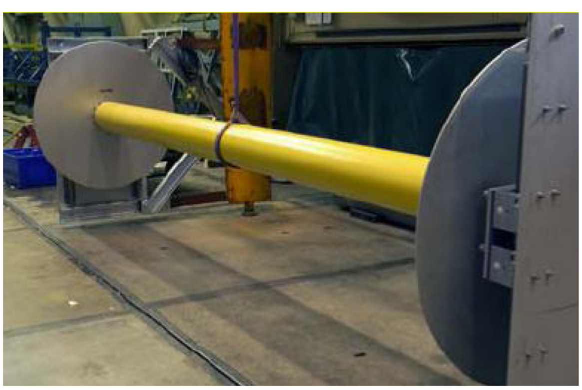

Fig. 1. The Smooth Stationary Cylinder.

bulent. It was concluded from the studies that the drag crisis phenomenon on the stationary smooth cylinder was not captured by the URANS methods (ITTC Ocean Engineering Committee Report [2]). It is well known that the drag crisis is caused by the instability of separated shear layer in the critical Reynolds number regime ($2 \times 10^5 < Re < 5 \times 10^5$). At the critical Reynolds numbers, the transition points are very close to the points of flow separation. As a result, the shear layer eddies cause the mixture of flow in the boundary layer and the flow separation is delayed. The delay of flow separation leads to the reduction of the drag coefficient. Since numerical methods based on two-dimensional URANS solvers are inadequate to simulate this physical phenomenon, it is necessary to extend the benchmark studies by including other CFD methods.

The 27th ITTC Ocean Engineering Committee extended the VIV benchmark studies by including the detached eddy simulation (DES) and the large eddy simulation (LES) methods. The CFD solutions were compared with the model test results for a circular cylinder. An overview of the model tests carried out by MARIN, test cases, the comparison of experimental and numerical results, as well as conclusions and recommendations, are presented in the paper.

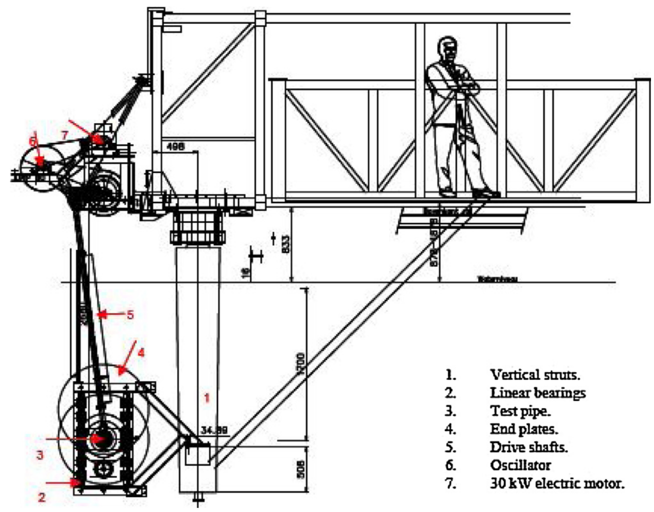

Fig. 2. High Reynolds Number VIV Test Apparatus by MARIN.

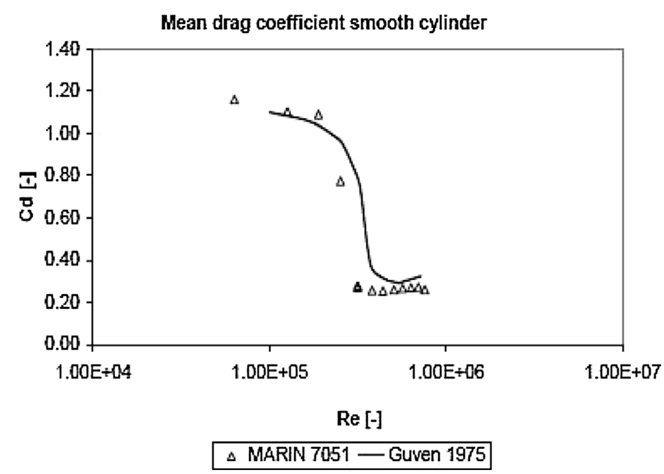

Fig. 3. Drag Coefficient for the Smooth Cylinder.

Table 1
Participants of the Benchmark Studies.

	Organization	Country
1	China Ship Scientific Research Centre	China
2	Seoul National University	Korea
3	Samsung Ship Model Basin	Korea
4	Memorial University	Canada
5	Inha University	Korea
6	University of Iowa	USA
7	University of Southampton	UK
8	Shanghai Jiao Tong University	China

2. Experimental data

As reported in the ITTC Ocean Engineering Committee Report [2], the benchmark experimental data for the VIV of a stationary circular cylinder was provided by MARIN. The rigid cylinder is 200 mm in diameter and 3.52 m in length (Fig. 1). The cylinder was suspended from the carriage about 1.7 m below the calm water surface. The VIV test apparatus is shown in Fig. 2. The towing tank of MARIN is 4 m deep, 4 m wide and 210 m long. The cylinder was towed horizontally by the carriage at various speeds. Details of the tests can found in the work of de Wilde and Huijsmans [3], de Wilde and Huijsmans [4], de Wilde et al. [5] and de Wilde et al. [6]. As an example, the measured drag coefficient for the smooth stationary cylinder is presented in Fig. 3.