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Uncertainties related to predictions of loads and responses for ocean and offshore structures

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A B S T R A C T

This paper discusses uncertainties related to the prediction of loads and responses for ocean and offshore structures in accordance with the findings by the Ocean Engineering Committee of the International Towing Tank Conference (ITTC). The parameters that may cause uncertainties in ocean engineering model tests, full-scale tests and numerical simulations are presented in terms of physical properties of the fluid, initial conditions, model definition, environment, scaling, instrumentation and human factors. Emphasis is given to the uncertainty sources in model tests involving deepwater mooring lines, risers and dynamic positioning systems and the need for quantifying them. A methodology for uncertainty analysis is described according to the International Organization for Standardization (ISO) Guidance for Uncertainties in Measurement (GUM). As an example of application, the combined and expanded uncertainties in the model tests of a moored semi-submersible platform were assessed and quantified in terms of motion responses, air gap and mooring line tensions. It is concluded that the quantification of uncertainties may be challenging in model tests and numerical simulations of ocean and offshore structures. It is particularly challenging in extrapolating model test results to full scale and utilizing complex numerical models, especially if the effects of hydrodynamic nonlinearities are significant.

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1. Introduction

The prediction of loads and responses is of importance in the design and operation of ships and offshore structures in the ocean environments. Uncertainties in the prediction are one of the main concerns of the shipping and offshore industry.

The responses of structures in ocean environments can be predicted using model tests, numerical simulations and full-scale tests. There are many parameters that cause uncertainties in the experiments and numerical simulations. It is important to identify these parameters and quantify the uncertainties.

The International Ship and Offshore Structures Congress (ISSC) and the International Towing Tank Conference (ITTC) jointly held a workshop in 2012 with an aim to understand the uncertainties in the description of environment, predictions of loads and responses of marine structures, and risk assessment and mitigation in design and operation. As one outcome of the Workshop, this paper presents the uncertainties related to predictions of loads and responses for ocean and offshore structures identified by the ITTC Ocean Engineering Committee. The focus is on uncertainties related to tests and simulations of bottom-founded structures, stationary floating structures with mooring lines or dynamic positioning systems, and renewable energy systems.

There have been many model tests, full-scale experiments and numerical simulations on ocean and offshore structures in recent years. For example, Morgan and Zang (2010) investigated the use of a computational fluid dynamics (CFD) software suite for the simulation of focused wave packets interacting with a vertical bottom mounted cylinder. Yang et al. (2010) reported on the experimental study of the scour around jacket offshore wind turbine foundations in shallow water and in different wave and current conditions. The effect of scour mitigation devices was

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Nomenclature

EA	mooring line axial stiffness
EI	mooring line bending stiffness
DOF	degree of freedom
f	an experimental result
ISO	International Organization for Standardization
ISSC	International Ship and Offshore Structures Congress
ITTC	International Towing Tank Conference
RAO	response amplitude operator
T_2	measured tension of mooring line #2
T_8	measured tension of mooring line #8
T_2'	tension RAO of mooring line #2
T_8'	tension RAO of mooring line #8
t_{95}	coverage factor at 95% confidence level.
$\mathbf{x}_n$	measured variables
x_3	measured heave
x_3'	heave RAO
x_{ag}	measured air gap
x_{ag}'	air gap RAO
u_c	combined uncertainty
u_e	expanded uncertainty
u_f	uncertainty of experimental result, f
η_a	wave amplitude
ν_{eff}	effective number of DOF
ν_i	estimated number of DOF

investigated. Roos et al. (2009, 2010) reported on the experimental study of wave impacts on elements of a gravity-based structure (GBS), composed of submerged storage caissons combined with four surface piercing vertical cylinders, in relatively shallow water. The wave impact loads on deck and the loads on vertical columns were successively investigated. Hussain et al. (2009) presented the measured steady drift force and low frequency surge motions of a semi-submersible model. A complete review of recent tests and numerical simulations of bottom-founded structures, stationary floating structures and renewable energy systems can be found in the final report of Ocean Engineering Committee, 26th ITTC (2011).

In this paper, parameters that may cause uncertainties in ocean engineering model tests, full-scale tests and numerical simulations are identified in terms of physical properties of fluid, initial conditions, model definition, environment, scaling, instrumentation and human factors. Parameters with dominant contributions to uncertainties in model tests involving deepwater mooring lines and risers and dynamic positioning systems are discussed. A uncertainty analysis methodology is described according to the ISO guidance. As an example, the uncertainty analysis method was applied to the tests of a moored semi-submersible platform model. The combined and expanded uncertainties were quantified in experimental results including motion responses, air gap and mooring line tensions. Challenges have also been identified in quantifying the uncertainty sources in tests and numerical simulations of ocean and offshore structures.

2. Parameters causing uncertainties in ocean engineering tests

Various methodologies can be applied to predict the response behavior and loads acting on ocean and offshore structures, including model experiments, full-scale measurements and theoretical methods. A comprehensive review of these methods can be found in Hirdaris et al. (2014). There are many parameters that can cause uncertainties in tests and numerical simulations based on these methods. The parameters causing uncertainties in ocean engineering model tests, full-scale tests and numerical simulations are discussed below and presented in Table 1 according to the categories of physical properties of fluid, initial conditions, model definition, environment, scaling, instrumentation and human factors.

2.1. Model tests

A review of issues associated with accuracy of physical modeling based on model tests can be found in the work of Vassalos (1999). In terms of categories listed in Table 1, sources of uncertainties in model tests are described below.

In the category of physical properties of water, these parameters include viscosity, density, temperature, surface tension, aeration, seeding or contamination.

The initial test conditions, such as remaining waves, circulation and turbulence in the tank from previous tests, can cause uncertainties.

There are many parameters in the model definition. For models with mooring lines and risers, the uncertainties can be caused by bottom friction of mooring lines, truncation of mooring lines, length, diameter, weight distribution, stiffness distribution, structural scaling, friction in bearings, location of anchor point, fairlead position, and pretension. The hull geometry and its GM value with and without mooring lines/risers, the inertia and stiffness properties, the topside geometry, the surface roughness, the thruster geometry and control systems, as well as the speed and the heading of the model are also the key parameters.

In terms of environment effects, the key parameters include wave conditions which are usually only measured at defined points, parasitic waves on shallow water, variation of current in time and space, wind conditions in terms of homogeneity and profile, wave-maker control, wave reflection from beaches and model, interaction between wind and waves, refraction due to uneven seabed on shallow water, wave–current interaction, and

Table 1
Uncertainty sources.

Method	Category	Example of source
Model tests	Physical properties of fluid	Viscosity
	Initial test conditions	Remaining waves
	Model definition	Hull geometry
	Environment	Wave modeling
	Instrumentation	Sensors
	Scaling	Viscous effect
	Human factors	Manual heading control
Full scale tests	Physical properties of fluid	Density
	Environment	Wave measurement
	Instrumentation	Position and synchronization
	Human factors	Crew behavior
Numerical modeling	Chosen governing equations	Limitation on describing the physics
	Numerical methods	Level of approximation
	Numerical implementation	Grid generation and distribution
	Calibration of parameters	Empirical parameter input
	Computing infrastructure	Computing capacity
	Human factors	Understanding of numerical model

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