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Sea state conditions for marine structures' analysis and model tests

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ABSTRACT

The study reviews, based on the state-of-the-art findings, some uncertainties associated with wave data and models currently used in design and operation procedures of ship and offshore structures. Although the same basic principles prevail for hydrodynamic loads on ships and offshore structures, actual problems and methods for assessing these loads in the design and operation stage are not the same. Different wave data and models are used for specifying design and operational criteria for these two types of platforms and different uncertainties are related to them. Wave data and models used to define sea state characteristics are discussed and particular attention is given to the associated sources of uncertainties. Some weaknesses of wave input used in design and operational procedures for marine structures are pointed out. Focus is also given on uncertainties related to model tests as tank testing is an important supporting tool for design and operation. Impact of some selected uncertainties on wave description and wave loads is demonstrated by examples.

1. Introduction

Enhancing safety at sea through quantification of uncertainties associated with wave description has been increasing within the shipping and offshore industries in the last decades, although the shipping industry has tended to lag behind the offshore industry. This trend has also been recognised by the ISSC (International Ship and Offshore Structures Congress) Committees I.1 Environment for some time and received special attention by the 2009, 2012 and 2015 Committees I.1 (see ISSC (2009, 2012, 2015)).

Today the demand for closer cooperation between metocean, hydrodynamic and structural groups is very high in marine engineering, and led to the initiation of the 1st Joint Workshop UMSOS (Uncertainty Modelling for Ships and Offshore Structures) on uncertainty associated with assessment of ship and offshore structures organised by ISSC I.1 and I.2 Committees and the ITTC (International Towing Tank Conference) Sea Keeping and Ocean Engineering Committees in Rostock, 8 September 2012. A Special Issue with papers from this workshop was published in Ocean Engineering, Hirdaris (2014). It was found that the joint workshop was mutually beneficial for many common interests of academia and the marine industry. Through the 1st Joint Workshop and discussion afterward, the structural loads on ships and offshore structures in waves was chosen as the topic of the 2nd Joint ITTC-ISSC Workshop organized by ITTC Sea Keeping Committee which took place on 30 August 2014 in Copenhagen. The workshop focused on the wave-induced motions and structural loads on ships and offshore structures, including a computational benchmark test for a large modern ship. The findings which addressed wave description presented at this workshop are reported herein.

Description of marine environment forcing conditions includes waves, wind, current, sea water level and ice. For waves a sea state is commonly defined by integrated wave parameters, such as significant wave height and wave period, wave spectra and/or distributions of individual wave parameters (e.g. a distribution of wave crest). Characteristics of a sea state are region and location dependent and for a limited period of time they vary in a stationary way. They represent an important input to specification of design and operational criteria of ships and offshore structures as well as for the definition of model testing programs in tanks.

Many marine structures' loads are waves dominated therefore wave description and uncertainties associated play a central role in

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the assessment of loads and responses of marine structures as well as in model testing, and is also given focus herein. Although the same basic principles prevail for hydrodynamic loads on ships and offshore structures, actual problems and methods for assessing these loads in the design and operational stage are not the same. Different wave data and models are used for defining design and operational criteria for these two types of structures and different uncertainties are related to them. Model tests represent an important supporting tool for marine structures' design and operations and for specification of model uncertainty. Wave input used in laboratory experiments will significantly influence loads and motions of marine structures being tested.

The present paper gives an overview of wave data and models defining sea states used currently for design and operations of ship and offshore structures, and discusses associated uncertainties, viewing some of them in more details. The study is illustrated by selected examples and points out weaknesses of wave input applied in assessment of loads and motions of marine structures. The aim of these investigations is to bring further awareness within the shipping and offshore industry to some of the uncertainties in wave description adopted in marine structures' assessment, using the state-of-the-art findings.

The study does not cover smaller crafts and marine renewable energy structures as they were not addressed by the 2nd Joint ITTC-ISSC Workshop, however, uncertainties associated with metocean description presented herein apply also to these types of structures.

The paper is organised as follows. Section 2 is dedicated to definitions of uncertainties; Section 3 shows how the sea states characteristics are established and discusses each step of this process. Uncertainties associated with wave data are addressed in Section 4 while in Section 5 assessment of sea state characteristics is given. Section 6 is dedicated to wave description in a sea state, Section 7 to model tests and in Section 8 models used in design and operational procedures of marine structures are discussed. The paper closes with conclusions, recommendations and references.

2. Definitions of uncertainties

Different definitions of uncertainties can be found in the literature and are applied by different scientific and engineering groups. Herein we adopt the definitions used by the structural reliability community which have been developed having Structural Reliability Analysis (SRA) in mind.

Uncertainty related to metocean description may be classified into two groups: aleatory (natural) uncertainty and epistemic (knowledge based) uncertainty. Aleatory uncertainty represents a natural randomness of a quantity, also known as intrinsic or inherent uncertainty, e.g. the variability in wave height over time. Aleatory uncertainty cannot be reduced or eliminated. Epistemic uncertainty represents errors which can be reduced by collecting more information about a considered quantity and improving the methods of measuring it. Following Bitner-Gregersen and Hagen (1990), epistemic uncertainty may be divided into: data uncertainty, statistical uncertainty, model uncertainty and climatic uncertainty. This classification is adopted herein.

Data uncertainty is due to imperfection of an instrument used to measure a quantity, and/or a model applied for generating data. Such measurement uncertainty is usually given by a manufacturer of an instrument. It can also be evaluated by a laboratory test or full scale test (calibration). If a quantity considered is not obtained directly from the measurements but via some estimation process (or simulation), e.g. significant wave height, then the measurement uncertainty must be combined with the estimation or model uncertainty by appropriate means.

Statistical uncertainty (sampling variability) is mostly related to the quality and consistency of the analysed data sample. It is for instance due to a limited number of observations of a quantity, to the existence of regions or time periods with missing data, or other sampling biases.

Model uncertainty is due to imperfections and idealisations made in physical process formulations implemented in the models as well as in choices of probability distribution types and fitting techniques applied for estimation of distribution parameters (e.g. the least squared methods, the maximum likelihood method, the method of moments). Several errors can contribute to model uncertainty. Errors can be defined as the ratio between the true quantity and the quantity as predicted by the model. A mean error value not equal to 1.0 expresses a bias whilst the standard deviation expresses the variability of the predictions by the model. Experimental tests or the average values of recognised models (or weighted models) are often used as a reference value (the true value).

Climatic uncertainty (or climatic variability) addresses the representativeness of a measured or simulated metocean variable history for the future time period in the area for which design or operational conditions need to be provided. The climate uncertainty is due to the natural variability of met-ocean climate and anthropogenic climate change, and can be regarded as a model uncertainty.

Environmental description will be affected by all types of epistemic uncertainties but to a different degree depending on data and models applied. Quantification of uncertainty of a considered quantity requires estimation of a systematic error (bias) and precision (random error), see Bitner-Gregersen and Hagen (1990). It is not an easy task because the true value τ, say, is usually unknown and needs to be assumed. Sparse literature systematically quantifying uncertainties can be found, although many efforts have been made in comparing different environmental data sources and models world-wide.

3. Sea state conditions

Wave description commonly provides information about total seas, which can be a superimposition of various wave systems, namely one wind sea and one or more swells, and is region and location dependent. It often employs a mixture of mathematical, probabilistic, empirical and statistical models. The following "decoupling" approach is commonly used. It is assumed that for a limited period of time and in a particular geographical region wave conditions vary in a stationary way called sea state. Wave conditions in a sea state can be described by means of mathematical models depending on a number of characteristic sea state parameters. Changes of sea state parameters, such as significant wave height, spectral/zero-crossing wave period and mean wave direction which vary more slowly than wave surface elevations in a sea state are modelled by means of probabilities. The final description of wave conditions for design and operations is obtained by combining the statistical/probabilistic models for sea states' evolution (long-term statistics) with the statistical/probabilistic description of waves in a sea state (short-term statistics). Information from phase-average wave models and phase-resolving wave models is utilized often in this process. Finally, in addition to the set of integrated (global) parameters, a sea state description generally comprises the wave spectrum as well as information on wave directional spreading for total sea, wind sea and swell, see DNV (2014).

Statistical description of sea states classically required for design of marine structures and management of marine operations is