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Joint description of waves and currents applied in a simplified load case

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ABSTRACT

In order to perform a more accurate analysis of marine structures, joint probability distributions of different metocean parameters have received an increasing interest during the last decade, facilitated by improved availability of reliable joint metocean data. There seems to be no general consensus with regard to the approach of estimating joint probability distributions of metocean parameters and a general overview of recent studies exploring different joint models for metocean parameters is presented. The main objective of this article is twofold: first to establish a joint distribution of significant wave height and current speed and then to assess the possible conservatism in the Norwegian design standard by applying this joint distribution in a simplified load case. Based on NORA10 wave data and simulated current data, a joint model for significant wave height and current speed at one location in the northern North Sea is presented. Since episodes of wind-generated inertial oscillations are governing the current conditions at this location, a joint conditional model with current speed conditional on significant wave height is suggested. A peak-over-threshold approach is selected. The significant wave height is found to be very well modelled by a 2-parameter Weibull distribution for significant wave height exceeding 8 m, while a log-normal distribution describes the current speed well. This model is used to Monte-Carlo simulate joint significant wave heights and current speeds for periods corresponding to the ultimate and accidental limit states (ULS and ALS), i.e. 100 and 10 000 years. The possible conservatism in the Norwegian design standard is assessed by a simplified case study. The results give a clear indication that the Norwegian design standard in not necessarily conservative, neither at ULS nor ALS level.

1. Introduction

Knowledge of the extreme meteorological and oceanographic (metocean) conditions and loading is required in both design and operation of marine structures such as offshore oil- and gas-producing facilities, wind power plants and pipelines. Design codes stipulate that offshore structures should be designed to exceed specific levels of reliability. To define extreme metocean loading, extreme metocean design criteria, primarily wind, waves and currents, must be specified. Accurate estimates of environmental design conditions, based on measured and/or hindcast data are of fundamental importance to the reliability of offshore structures over time. Thus, reliable metocean design criteria are essential in both design and operation of marine structures.

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In order to perform a more accurate analysis of marine structures, joint probability distributions of different metocean parameters have received an increasing interest during the last decade, facilitated by improved availability of reliable joint metocean data. However, there still seems to be no general consensus with regard to the approach of estimating the joint probability distributions of metocean parameters and several different approaches are put forward. Jonathan and Ewans [1] gave a good theoretical overview of multivariate modelling of extreme ocean environments and guidelines for validity, but pointed out that "unfortunately there is as yet no unifying approach, and the literature is rather confusing". Ewans and Jonathan [2] concluded that specification of joint design criteria has often been somewhat ad hoc, based on experience and intuition and thus fairly arbitrary combinations of independently estimated extreme values. Vanem [3] demonstrated that there were large variabilities and thus large uncertainties in the estimated joint models due to different modelling choices, even for the same data set, and concluded that multivariate modelling of metocean conditions remains a challenge, even in the bivariate case.

For the Norwegian continental shelf (NCS), the design standard NORSOK N-003 [4] define the characteristic metocean loads and load effects in terms of their annual probability of exceedance, q. The requirements for ultimate and accidental limit state (ULS, ALS) for metocean actions on an offshore structure are $q \leq 10^{-2}$ and $q \leq 10^{-4}$, respectively. These requirements refer to the resulting metocean load obtained by accounting for simultaneous occurrence of metocean parameters such as wind, waves and currents. These parameters are not fully correlated and in order to utilize this for design, simultaneous data of high quality covering several years are required.

In lack of sufficient simultaneous metocean data, a combination of metocean parameters assumed to be conservative is recommended [4], but the degree of conservatism is not very well known. To utilize in design of offshore structures that the occurrence of metocean parameters is not fully correlated, the latest edition of NORSOK N-003 recommends at least three years of simultaneous wind, wave and current data. For Norwegian waters, high-quality measured and hindcast wind and wave data covering several decades are available. For currents, measured data is considered state-of-the art, but current measurements are rarely performed for more than one year. No available current hindcast for NCS is considered to have sufficient quality to base design criteria on. Thus, the availability of current data will be the limiting factor for estimation of joint distributions of wind, waves and currents.

Motivated by the need for high-quality current data of long enough duration for estimation of joint environmental conditions, extensive current measurements have been done at five locations in the northern North Sea [5]. The metocean measurement programme was initiated early 2011 and completed late 2015, i.e. a total duration of about 4.5 years. Simultaneous waves and current profiles were measured. Challenges related to the quality of measured current data have been reported and it is suggested that the accuracy of measured current data might not be as good as the user expects [6]. A new current hindcast has also been developed [7]. Comparison of available measured data in the northern North Sea and the new current hindcast showed a good correspondence. However, the quality of this current hindcast is not as good as the quality of available wind and wave hindcast for NCS and must be used with caution. Nevertheless, this hindcast constitute a very promising starting point for further development of an even better current hindcast for the northern North Sea. In summary, neither the measured nor the hindcast current data for the northern North Sea succeeded completely in providing the appropriate current data needed to establish joint distributions of metocean parameters in the northern North Sea. Considering the quality of measured current data, rather than to measure current simultaneously with wind and waves for a long period, it could prove to be more appropriate and prosperous to develop high-quality hindcast current data covering several years, validated with shorter periods of current measurements, to obtain adequate current data for estimation of joint environmental conditions.

The measured current data showed that currents from wind-generated inertial oscillations dominate the current conditions in the some parts of the northern North Sea, specifically in the area 59° to 60°N, 2° to 3°E. Following this, a simple model for wind-generated inertial oscillations has been applied to simulate current data of a long duration. Tuned with appropriate site-specific parameters for the northern North Sea and validated against available measured current data, this simple model generated current data of good enough quality.

The main objective of this paper is to establish a joint distribution for waves and currents based on simultaneous hindcast wave data and simulated current data. This joint description will be used to assess the possible conservatism in the N-003 recommendation for a selected load case. A simplified parametric load model for quasi-static loads on a jacket, generated from waves and currents, is assumed. The ULS and ALS loads are then estimated based on (1) the N-003 recommendation for combination of metocean parameter and (2) the metocean data simulated from the joint distribution of waves and current.

This article is outlined as follows: First, a general literature overview of recent advances in joint modelling of metocean parameters is given. Next, the available wave and current data in the northern North Sea are briefly described, before the joint probability distribution of waves and currents are presented. Then, the possible conservatism in N-003 requirement is assessed for a selected, simplified case study. At last, a summary is made.

2. Joint models for metocean parameters

There is no unifying approach to joint modelling of metocean parameters. Several different approaches are put forward in the literature and strongly advocated by their users. Comparisons of the different approaches based on specific case studies are barely available and this makes it difficult to "benchmark" the different approaches. Each group of researchers seems to have their preferred approach and reason for this.

A general overview of recent studies exploring different joint statistical models for offshore environmental conditions are given below. For simplicity, bivariate statistical models are often represented rather than the multivariate generalisations, but these are easily extended beyond two dimensions to multivariate models.