Ocean Engineering 156 (2018) 318–332

Contents lists available at ScienceDirect

Ocean Engineering

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

Current conditions in the northern North Sea

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ARTICLE INFO

Keywords:
Currents
Measurements
Northern north sea
Inertial oscillations
Seasonal current conditions
Extreme currents

ABSTRACT

In order to acquire sufficient simultaneous data to establish joint distributions of waves and currents for design, an extensive measurement programme of simultaneous waves and current profiles has been performed for approximately 5 years at several locations in the northern North Sea. The measured current data have been found to be more inaccurate than the specified accuracy of the instruments. However, the measured current data still give a good over-all description of the main features of the current conditions in the northern North Sea. Variations in current conditions are seen between the different measurement locations. At the southernmost locations, wind-driven currents, i.e. inertial oscillations, are the governing current conditions and contribute to larger current speeds during summer than in the spring and fall, both operational and extreme. At all locations, year-to-year variation in estimated extreme current speeds based on different individual years are larger than expected, indicating that current measurements for considerably more than one year is required for reliable estimates of extreme current conditions for design of offshore structures. These results highlight the need for a better understanding of the current conditions in order to account for the uncertainties associated with these in design of offshore structures.

1. Introduction

Knowledge of the extreme meteorological and oceanographic (metocean) conditions and loading is required both in 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.

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 (2013) 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 (2014) 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 (2016) 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. The most widely studied joint probability distribution is the distribution of significant wave height and wave period, both zero up-crossing and peak, and several studies have considered different approaches, e.g. Haver (1985); Mathisen and Bitner-Gregersen (1990); Bitner-Gregersen and Guedes Soares (2007); Johannessen et al. (2002); De Michele et al. (2007).

Available studies of the joint probability of waves and currents in the surface of the water column are very few, probably due to the lack of simultaneous measured wave and current data and the complicated, far from fully understood, wave-current interaction mechanisms. Two studies (Gordon et al., 1985; Heideman et al., 1989) investigate the

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https://doi.org/10.1016/j.oceaneng.2018.03.025
Received 7 October 2016; Received in revised form 6 March 2018; Accepted 7 March 2018

Abbreviations

ADCP acoustic Doppler current profiler
AQD Nortel 600 kHz Aquadopp
CM04 RPS Metocean Current Meter 04
Cs current speed
Cs0 I current speed threshold
CsDir current direction
CurVeS Current Verification Study
Hs significant wave height
LR ADCP Teledyne RD Instruments 75 kHz Long Ranger ADCP
NDP Norwegian Deepwater Programme
QM ADCP Teledyne RD Instruments 150 kHz Quartermaster ADCP
qq-plot quantile-quantile plot
RCM7 Aanderaa Recording Current Meter 7
WH ADCP Teledyne RD Instruments 1200 kHz Workhorse ADCP

relationship of extreme waves and currents based on simultaneous measurements at Tromsøflaket and establish very simplified joint distributions of waves and currents further used in design and load calculations for offshore structures. Another joint environmental model for long term response calculations at the NCS was proposed by Bitner-Gregersen and Haver (1991), incorporating both wind speed, current speed, several wave characteristics and water level. This model was later extended to include the possibility of environmental effects approaching from different directions (Bitner-Gregersen, 1996). Liu et al. (2002) presented a joint probability design method based on a stochastic simulation technique to determine the combined environmental design criteria of wave, current and wind and found this approach to give less conservative and more reasonable design criteria when applied different marine structures. Dong et al. (2007) proposed and applied a Trivariate Nested Logistic Distribution to estimate joint probability of wind speed, significant wave height and current velocity in the Bohai Sea. This approach is suggested to be more objective and reasonable when environmental extreme values for design are to be estimated. In order to derive joint extremes of wave, wind and current and IFORM contours, Nerzic et al. (2007) study 3 years of measurements offshore Angola. The initial data analysis is emphasized and it is not clear how the joint extremes are derived. Sagrilo et al. (2011) utilize 2 years of simultaneous measured environmental data offshore Brazil to create joint probability models of wave, wind and current parameters, 10 parameters in total, based on the Nataf transformation.

For the Norwegian continental shelf (NCS), the design standard NORSOK N-003 (NORSOK, 2017) 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 data, the Norwegian design regulations, NORSOK STANDARD N-003 Edition 3 (NORSOK, 2017), recommend a combination of metocean parameters assumed to be conservative, but the degree of conservatism is not very well known. To utilize in design of offshore structures that the occurrence of extreme wind, waves and currents are 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 simultaneous wave and current measurements have been done at five locations in the northern North Sea. 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. Since these measurements comprise an exceptional measured current data set, is this paper dedicated to describes the current measurements in the northern North Sea with focus on the seasonal and extreme current conditions. The year-to-year variability in current conditions, often not possible to consider at all due to limited current measurements, are also investigated. A joint distribution of waves and currents are presented in a separate paper (Bruserud et al., 2018).

This paper is outlined as follows: First, an overview of the measured current data, both the measurement programme and the quality control of the data, is given in the next section. Then, a general description of the current conditions is presented, followed by the seasonal current conditions, before the extreme current conditions are considered. At last, a summary is made.

2. Data

2.1. Measurement programme

A metocean measurement programme of waves and currents at five locations in the northern North Sea, see Fig. 1, was initiated early 2011. First, a pilot phase at Location 1 was performed from January to May 2011, before the main phase with measurements at all five locations started in May 2011. At Location 3, the measurements were ended by the end of 2013 and due to this, these measurements are not considered further here. At the other locations the measurements were completed in October 2015, i.e. a total duration of about 4.5 years. An overview of the measurement locations, water depths and data returns is given in Table 1. Due to bad weather during the winter season 2013/2014, it was not possible to re-deploy the measurement instruments at location 2, 4 and 5 after servicing and thus no measured data are available. According to Table 1, successive problems with the surface mooring at Location 1 have been experienced, causing gaps in these data. The reasons for the disruptions have been marine operations at the oil field close to the mooring, problems with transmittance of data and the surface buoy parting and drifting away from the rest of the mooring. Based on this, this surface mooring was relocated in June 2014 to another location close by.

The measurements at each location have been performed with the same generic mooring design, which consisted of one surface mooring and one seabed mooring. All measured data were transferred in real-time by satellite.

During the pilot phase at Location 1, the surface mooring consisted of a surface buoy equipped with sensors for meteorological measurements 3 m above mean sea level and surface wave measurements. From a frame 7 m below the buoy, sea temperature and salinity were performed and also measurements of current speed (*Cs*) and direction (*CsDir*) throughout the water column. The seabed mooring was designed to measure all the same parameters, 7 m above seabed. A schematic outline the mooring configuration and also the instrument types are given in Fig. 2. More details of the different measurement instruments are given in Appendix I.

Very noisy periods of current data measured by the current meter