Ocean Engineering 168 (2018) 83–94

Contents lists available at ScienceDirect

Ocean Engineering

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

# Full-scale validation of the hydrodynamic motions of a ship derived from a numerical hindcast

I.A. Milne[a,*], M. Zed[b]

[a] Oceans Graduate School, The University of Western Australia, Crawley, WA, 6009, Australia
[b] Woodside Energy Limited, Perth, WA, 6000, Australia

ARTICLE INFO

*Keywords:*
Directional wave spectra
Numerical wave hindcast
Ship hydrodynamics

ABSTRACT

New measurements from a drillship operating in a swell dominated region are used to demonstrate that generally reliable estimates of the hydrodynamic motions can be obtained from numerically hindcast directional wave spectra. Independent estimates of the directional wave spectra derived from the ship motions using a parametric approach are shown to be in close alignment with the hindcast spectra. Deviations between predictions and observations in this methodology are largely explained through the idealised nature of the hindcast spectra and limitations in the ability of the numerical model to capture swell arrival over the long fetch on approach to the project site, which is demonstrated through comparison of observed and modelled spectra. In general, the study provides encouraging support for the application of numerical hindcast techniques for vessel motion assessments, particularly for sites for which wave buoy measurements are not available.

## 1. Introduction

The safe and efficient operation of an offshore floating facility is critically dependent on its hydrodynamic response to the local wave conditions. For ship-shaped vessels, such as a drillship, depending on the incident wave periods and direction, large wave-induced resonant motions can be experienced in the open sea. Excessive heave, roll and pitch motions, in particular, can compromise the mechanical systems, restrict aviation operations and endanger the safety of personnel. For feasibility studies, quantifying the wave induced dynamic motions that a vessel is sensitive to, therefore, plays a critical role in evaluating its suitability for a particular site.

In an operational context, the methods of determining the operability of a floating facility have previously often been based on significant wave height thresholds. That is, the probability distributions of the significant wave height that are provided for a select region within industry guidance documents (e.g. (DNV, 2010)) are employed for assessment against a single parameter threshold. There are, however, several important shortcomings of this approach. The use of a single parameter such as the significant wave height generally provides an inaccurate representation of the complex sea states prevalent at offshore locations. The response of a floating body may be sensitive to wave energy at particular frequencies which cannot be readily deduced from this metric. The distributions also generally do not include details on seasonality. Furthermore, operability limits (installation, offtake, aviation etc.) are typically expressed in terms of tolerances on the vessel motion and not wave parameters. Given the variability in the wave response characteristics of different floating facilities, it is often difficult to obtain relevant sea state thresholds.

A more rigorous assessment of the suitability of the floating facility necessitates determining the dynamic motions from extensive records of the sea state which describe the wave amplitudes, periods and their directionality. To ensure that this is practically feasible to be employed operationally, the approach pursued must not only yield accurate results but be computationally efficient. This generally restricts the approaches to those which can be implemented stochastically rather than in the time domain. Computing the response from directional wave spectra and hydrodynamic transfer functions, which characterise the response of the ship to the waves, is an effective means of achieving this.

In many instances, particularly for exploration studies, long-term directional spectra from wave buoy measurements are, unfortunately, not available at the location of interest. This can pose a significant challenge for the practitioner attempting to compute the hydrodynamic vessel responses. Over the last decades, significant improvements in the accuracy and efficiency of numerical-based spectral wave models have, however, enabled long-term wave hindcast directional spectra data to become accessible. These models can, therefore, possibly circumvent

* Corresponding author.
*E-mail address:* ian.milne@uwa.edu.au (I.A. Milne).

https://doi.org/10.1016/j.oceaneng.2018.08.039
Received 26 March 2018; Received in revised form 16 July 2018; Accepted 23 August 2018
Available online 11 September 2018
0029-8018/ 

**Nomenclature**

| | |
|---|---|
| $H_i(\omega, \beta)$ | Complex-valued response amplitude operator (RAO) for motion $i = 3, 4, 5$ (heave, roll, pitch) |
| $H_s$ | Significant wave height (m) |
| $T_p$ | Peak spectral wave period (s) |
| $S(\omega, \theta)$ | Directional wave spectral density |
| $m_i$ | Statistical moment of $i^{th}$ order |
| $\beta$ | Wave direction relative to ship (°) |
| $\theta$ | Wave direction relative to compass heading (°) |
| $\omega$ | Wave radial frequency (rad s$^{-1}$) |
| $\eta_i$ | Most probable maximum displacement amplitude for motion $i$ |
| $\sigma_i$ | Standard deviation of displacement amplitude for motion $i$ |
| $\Phi_{ij}(\omega)$ | Cross-spectral density of motion responses $i$ and $j$ |

the need for observations at an offshore site or supplement measurements.

Third generation phase-averaged spectral wave models such as WAVEWATCH III (WW3) (Tolman, 1991); (Tolman, 2014) have proved particularly popular and are now widely utilised in both research and operational oceanography contexts. These models are based on solving the wave action density balance and parametrize the key physical processes associated with wave generation, growth and dissipation to estimate the directional wave spectral properties over a specified domain. Provided that the response characteristics of the floating facility to waves are known, such models can, therefore, potentially be employed to estimate the dynamic response statistics of the facility in lieu of observations of the sea state at the site.

Despite the potential attractiveness of employing a numerical approach for operability assessments, there are several salient points which the practitioner must consider. For instance, the vast majority of studies in which numerical wave models have been employed and validated have primarily focused on wind (sea) waves. Owing to their large inertia the first-order hydrodynamic responses of Floating Production, Storage and Offloading (FPSO) facilities or ship-shaped drillships are generally more sensitive to longer swells compared to wind waves. It is, therefore, essential to ensure that the swell energy is accurately simulated by the numerical model. As swells propagate over significant distances, this typically necessitates computations over spatially large domains and ensuring that appropriate source terms are employed to model the non-linear growth and dispersion of the swell.

Evaluating the capability of a numerical model to simulate this swell component of the spectra using field measurements is, therefore, essential if a hindcast approach is to be confidently employed to undertake feasibility assessments for offshore floating facilities. Some insights can be drawn from the study by (Milne et al., 2016), in which a numerical approach utilising a third generation wave spectral model was demonstrated to yield generally reliable estimates of the most probable maximum amplitudes of the first-order dynamic motions of a FPSO in a complex wave environment where strong swells were present. The response spectra were, however, not able to be compared due to limitations with the data acquisition systems. The study also demonstrated that the numerical wave hindcast could be utilised to deduce the heading of the turret-moored vessel, implying that reliable estimates of the mean wave drift loads could be obtained. However, as the mean-drift wave loads are generally dominated by the higher frequency wave components (Faltinsen, 1993) it is challenging to explicitly evaluate the performance of the swell hindcast from these results. Despite these encouraging findings there is, therefore, an apparent need for more extensive validation using field data and with a particular focus on the swells.

It is also important to appreciate that the use of a numerical hindcast approach in lieu of directional measurements from a wave buoy inherently adds another source of uncertainty to the computation of the vessel motions. To facilitate an evaluation of the approach it is, therefore, of interest to eliminate as many potential sources of error as possible. The previous studies which have incorporated field measurements in their analyses of vessel motions have generally been based on an FPSO or a cargo ship. The dynamic motions of these vessels, particularly in roll, can be affected by non-linearities associated with varying draft, heading and forward speed that can further complicate the validation of the models. By considering a stationary vessel with a constant displacement and heading, such as a dynamically positioned drillship and for which high quality motion data are generally available, these additional uncertainties can potentially be circumvented.

Furthermore, when attempting to evaluate the performance of a hindcast it is also useful to consider whether independent estimates of the directional wave spectra can possibly be derived from the motions of a ship itself using a wave-buoy analogy (see e.g. (Nielsen, 2017), (Milne and Zed, 2018)). In the absence of directional wave buoy measurements for direct comparisons with model wave spectra, these independent spectral estimates may be a valuable aid for verification. Deriving the directional wave spectra from a ship, however, is generally more challenging than obtaining these directly from a wave buoy. The effects of forward speed and a variable draft can complicate the analyses, which again suggests that a drillship could be an ideal vessel for utilising this technique. It is also important to acknowledge that only those wave components that the floating body is sensitive to can be reliably resolved following this approach. Due to the large inertia of a ship, the higher-frequency wave content (typically associated with wind waves) is effectively filtered out. However, since the higher frequency waves are unlikely to govern operability this is generally not of too great of concern.. Furthermore, it should be appreciated that for a dynamically positioned ship the long period horizontal motions (e.g. surge, sway and yaw) may be significantly affected by the actions of the thrusters. As such, these components of motion may not be reliable for determining the wave spectra using the wave buoy analogy.

To this end, this paper presents a case study whereby high-quality motion records from an operating drillship were used to evaluate the performance of a numerical-based approach to estimate the vessel motions. The objective of the study was to utilise fully directional wave spectra computed from a state-of-the-art numerical hindcast to, in particular:

- quantify the suitability of the model in terms of key motion statistics which may be used for operability assessments
- examine the reliability of the model for a range of representative sea states that may be experienced during the drilling operation and that the ship was sensitive to, including bi-modal swells.
- establish independent estimates of the wave spectra directly from the vessel motions using a wave-buoy analogy for comparison.

The study is intended to provide the offshore industry with a new set of results which may be used to assess the value of a numerical model for aiding operability assessments. Owing to its computational efficiency the model may be utilised to obtain long-term hindcasts of vessel motions and determine weather windows. Furthermore, it is useful to appreciate that the independent estimates of the wave spectra can be computed from the vessel motions at near real-time which can therefore be exploited during operations. The study significantly extends the earlier investigations of (Zed and Milne, 2018), in particular, by drawing on the study by (Milne and Zed, 2018) to derive the independent estimates of the wave spectra for comparisons with the hindcast spectra. Additionally, new measurements from a directional wave buoy acquired at a similar swell dominated site are compared