Response - Based Workability

Auteur : Morice Gomez, Rita Alejandra
Promoteur(s) : Rigo, Philippe
Faculté : Faculté des Sciences appliquées
Diplôme : Master : ingénieur civil mécanicien, à finalité spécialisée en "Advanced Ship Design"
Année académique : 2023-2024
URI/URL : http://hdl.handle.net/2268.2/22248

Response-based workability

Heavy Lift Vessel Performance Under Complex Sea States

submitted on 14 August, 2024

by

Morice Gomez Rita Alejandra

Supervisor:
Sijun Rao
DEME Offshore

First Reviewer:
Ph.D., Zhe, Li
Maître de Conférences
44470 Nantes
France

Second Reviewer:
Ph.D., Antoine, Ducoin
Maîtresse de conférences
44470 Nantes
France

[This page is intentionally left blank]

Contents

List of Figures

List of Tables

[This page is intentionally left blank]

DECLARATION OF AUTHORSHIP

I, **RITA ALEJANDRA MORICE GOMEZ** declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Where I have consulted the published work of others, this is always clearly attributed.

Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

I have acknowledged all main sources of help.

Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma.

I cede copyright of the thesis in favour of DEME Offshore.

Date: 14 August, 2024

Signature:

Rita Morice

[This page is intentionally left blank]

ABSTRACT

This research introduced a response-based workability approach, which refined go/no-go decisions by converting complex 2D wave forecast data into accurate vessel response predictions.

To obtain accurate vessel responses, 2D wave forecast data, derived from forecasting and historical metocean data (e.g.,ECMWF) or real-time wave measurement systems, were integrated with the linear transfer function. The 2D wave spectra provided a comprehensive view of energy distribution across both frequency and direction, enabling detailed analysis of spectral information for each wave train.

Workability calculations were conducted using both weather-based and response-based approaches. For the response-based method, operational windows were established by directly using the most probable maximum (MPM) responses obtained from detailed vessel response analysis. In contrast, the weather-based approach involved an operational assessment to determine and compare forecasted wave heights with allowable operational wave heights.

The comparison of these methodologies demonstrated that the response-based workability approach extended operational windows and revealed critical challenges not identified by the weather-based method. During the tender phase, this approach facilitated the selection of more conservative operational windows, thereby mitigating risks and providing a clearer picture of operational constraints. In the operational phase, it offered crews detailed decision-making tools, highlighting potential challenges that weather-based data might overlook. For instance, it can identify critical responses even with low significant wave heights (H_s) if the wave frequency aligns with the vessel's critical response frequencies, potentially leading to resonance.

By integrating response-based workability with weather-based methods, this study improved operational assessments, offering a more comprehensive view of vessel performance and constraints. This approach enhanced decision-making and safety, with potential benefits for both planning and real-time operations, leading to better risk management and efficiency.

Keywords: Workability, 2D wave spectra, wave-by-wave analysis, frequency domain, most probable maximum response, linearities, non-linearities, spectral density

1 INTRODUCTION

Most offshore operations depend on a suitable weather window, defined by specific conditions such as wave height, which must remain below a set limit for a specified time period. This allowable wave height is determined through an operability study that simulates the operation using a standard wave spectrum, such as JONSWAP. The operational limits are then translated into a maximum allowable wave height as a function of wave period and direction. This approach is known as weather-based workability, which is a common practice in today's offshore industry.

However, the selection of a standard spectrum for modeling the sea state can introduce inaccuracies, potentially leading to over- or underestimation of workability, which may compromise safety or production. These inaccuracies can be mitigated by using a more complex sea state model, the 2D wave spectrum, derived from metocean data. The advantage of this model lies in its ability to handle non-linearities and accurately represent the energy content of the sea spectra. This model is obtained through third-generation models, such as those developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), which account for non-linear contributions directly through non-linear wave-wave interactions using the Discrete Interaction Approximation (DIA) method.

The scope of this research is to incorporate the 2D spectrum and, together with the response limits, transform the weather forecast into a motion forecast. This approach is known as Response-Based Workability. The main objective of this study is to evaluate whether this method can enhance the accuracy of vessel response predictions, thereby improving go/no-go decision-making. To achieve this objective, the research aims to develop a comprehensive methodology that calculates both response-based and weather-based workability and facilitates their comparison.

The central question driving this research is whether the implementation of the response-based methodology offers improved vessel workability predictions.

2 ORCAFLEX MODELING AND ANALYSIS

The selected vessel to implement the methodology is a Heavy Lift Vessel (HLV) commonly employed in various offshore wind farm installation projects was chosen. Two heavy lift operations during monopile installation are studied.

2.1 Calculation Methods in OrcaFlex

Dynamic analysis can be perform in OrcaFlex by time domain or by frequency domain, and their main difference are label in the table below:

Table 2.1: Selected periods and wave heights

Aspect	Frequency domain	Time Domain
Nonlinearity	Linearized	Direct
Integration	N/A	Explicit/ Implicit
Output	Spectral density	Time history
Data	Statistical	Deterministic
Time history	Synthesized	Direct

2.1.1 *Frequency Domain Analysis*

Frequency domain analysis in OrcaFlex employs linear transfer functions to analyze the system's response across specific frequencies. The non-linearities from the OrcaFlex models, such as winches, undergo linearization to derive the necessary linear transfer functions.

The linearization process involves transforming these nonlinear relationships into linear forms by evaluating the Jacobian matrix. This matrix represents the gradient or first-order derivative of the function at a specific point in the model's static state, excluding cases involving friction and drag. For instance, the system's stiffness is linearized using the tangent stiffness matrix computed after static analysis.

Selection Criteria for Dynamic Analysis Parameters

- **Frequency Domain Resolution:** The system's response was analyzed at the wave frequency.
- **Dynamic Loading Context:** This analysis captures the system's response to first-order dynamic loading driven by the stochastic wave elevation process.
- **Iterative Linearization:** While this model does not include drag, iterative linearization is a general requirement for frequency domain analysis to linearize the quadratic viscous drag load.
  - **Maximum Iterations:** Up to 100 iterations were performed to achieve convergence. The convergence criteria was selected to be 25×10^{-6} with a convergence damping factor of 0.2.

2.1.2 *Time Domain Analysis*

Time domain analysis encompasses the evaluation of all nonlinearities and can be executed through either explicit or implicit time domain integration schemes.

In the context of the simulation discussed in this section, implicit integration was employed, leveraging OrcaFlex's utilization of the generalized-α integration scheme.

This section highlights the key differences between time domain and frequency domain approaches and explains why frequency domain analysis is preferred for the proposed methodology.

To better understand the differences between both methods, four different cases were studied:

1. 2D wave spectra
2. Unidirectional Jonswap
3. Airy following wave
4. Airy beam wave

To select the 2D wave spectra, 1736 hours of wave forecast data were analyzed. The selection process involved filtering out all wave heights below the maximum design H_s specified in the *Weather Assessment Plan*, then selecting the most repetitive periods and identifying the highest wave amplitude for each. Subsequently, a modal analysis was performed to identify the natural periods and select the wave spectra closest to at least one mode. Table 2.2 presents the 6 filtered wave spectra, with the selected one for horizontal shift highlighted in green and for hammer lift in yellow.

Table 2.2: Selected periods and wave heights

Time	H_s (m)	T_p (s)	f_p (Hz)
2024-05-04 09:00:00	2.47	7.539	0.133
2024-05-04 18:00:00	2.1	6.727	0.149
2024-05-04 19:00:00	2.07	6.856	0.146
2024-05-04 20:00:00	2.12	6.6	0.152
2024-05-08 08:00:00	1.3	7.397	0.135
2024-05-08 09:00:00	1.28	5.355	0.187

2.1.3 *Wave Elevation Results*

The comparison of wave elevation for each case is shown in Figure 2.1. It can be observe a strong correlation between the results deliver from time and frequency domain, the RMS difference is null.

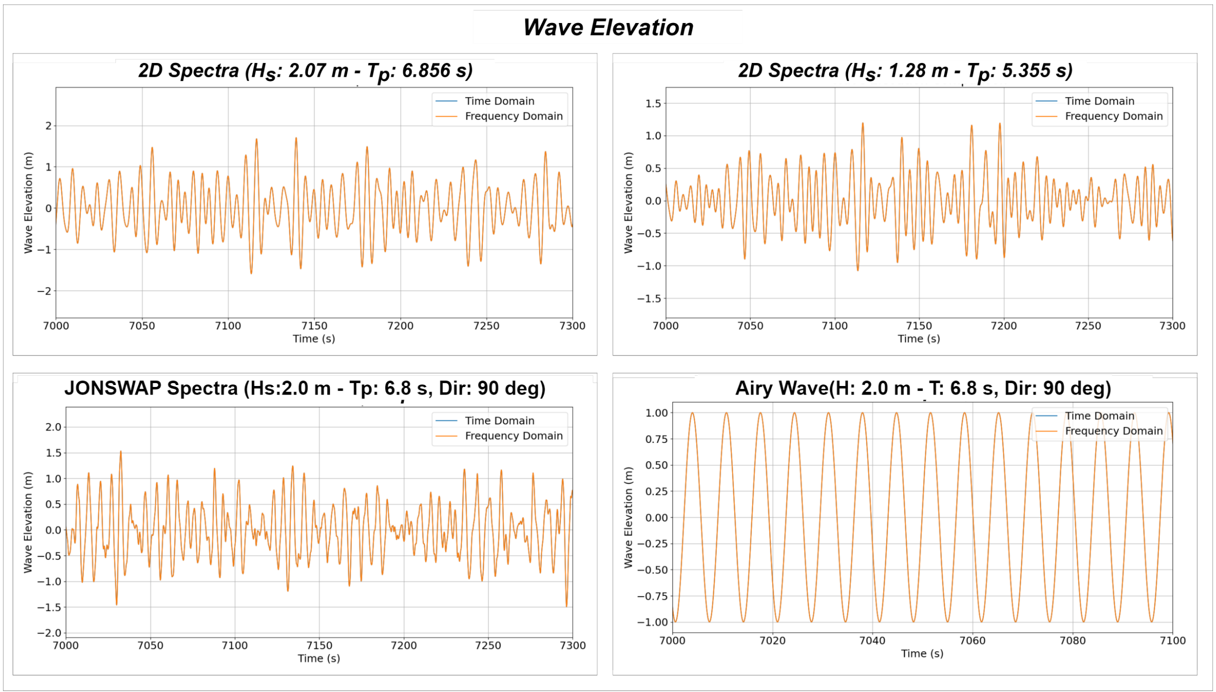

Figure 2.1: Comparison of sea elevation results between time domain and frequency domain methods

The spectral density, available only for 2D wave spectra and JONSWAP, will be presented for comparison to highlight differences between the two methods.

From Figure 2.2, it can be observed that there is a deviation in the peak frequencies for the 2D spectra, whereas the JONSWAP spectra show good alignment. This difference arises from the methods used to obtain the spectral density. OrcaFlex uses a parametric method to derive the PSD in the frequency domain and a Fast Fourier Transform (FFT) in the time domain.

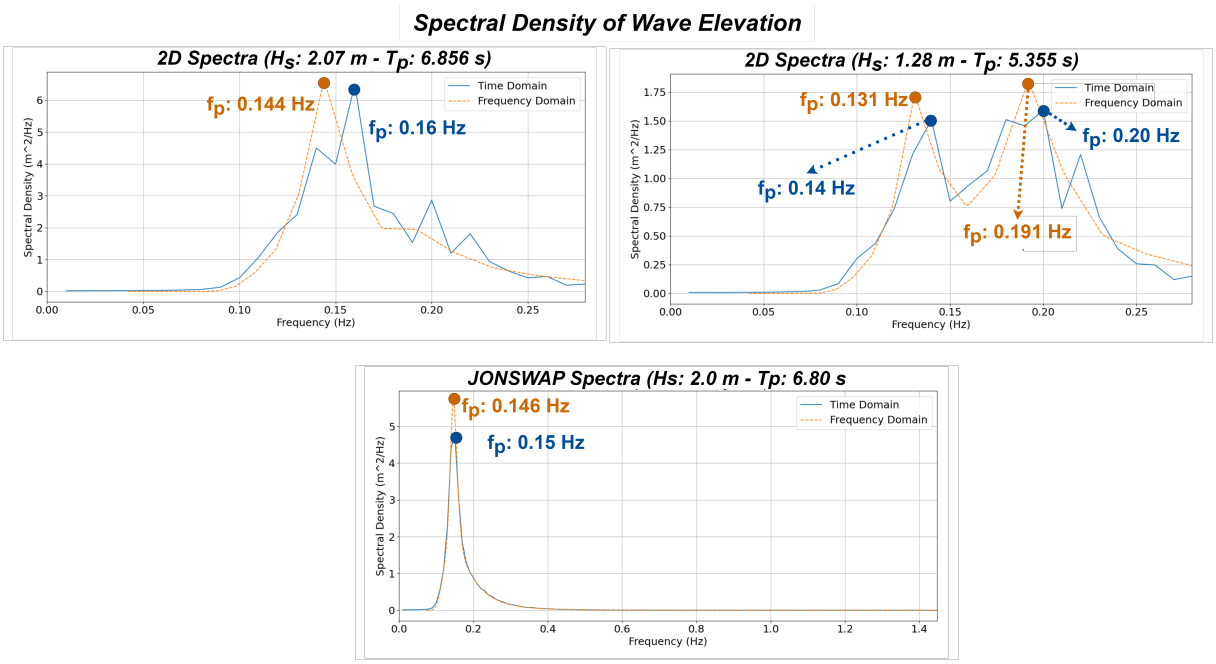

Figure 2.2: Comparison of the spectral density of sea elevation results between time domain and frequency domain methods

Parametric methods fit a predefined model to the data. The JONSWAP spectrum, with its distinct shape and parameters, enables a precise match between the model and actual wave spectra, ensuring strong correlation in the frequency domain.

In contrast, 2D spectra do not have a predefined shape, making it challenging to accurately fit a parametric model. This absence of an assumed initial shape can lead to discrepancies between the results obtained using the FFT method in the time domain and those from the parametric method in the frequency domain. In the time domain, the results typically show a peak frequency closer to the peak frequency of the spectra. However, in the frequency domain, although there is a peak aligning with the time-domain peak frequency, it is not the maximum frequency, as observed in the case of Hs: 2.07 m and Tp: 6.856.

Despite these differences, Table 2.3 demonstrates that the parametric method use to obtained the spectral density in frequency domain method captures the wave energy with good accuracy.

Table 2.3: Comparison of RMS Values from Spectral density results

Wave Input	Time Domain RMS m	Frequency Domain RMS m	Difference m	Relative Error %
2D Wave Spectra (Hs: 2.07 m, Tp: 6.856 s)	0.606	0.578	0.0286	4.95%
2D Wave Spectra (Hs: 1.28 m, Tp: 5.355 s)	0.395	0.95	0.0004	0.04%
JONSWAP Spectra (Hs: 2.0 m, Tp: 6.80 s	0.518	0.518	0.0001	0.01%

2.2 Discussion

- Using unidirectional, Airy wave, or complete 2D wave spectra (wave trains) provides consistent results between the time and frequency domains for wave elevation.
- The discrepancy in response results between the time and frequency domains depends on the presence of nonlinear effects. For sea states with significant nonlinear effects, the coherence between both analyses is reduced, affecting vessel responses correspondingly.
- Frequency domain simulations offer substantial efficiency gains over time domain simulations. For example, simulating Airy waves over a 3-hour period takes 2760.28 seconds in the time domain, compared to just 0.16 seconds in the frequency domain, highlighting a pronounced difference in computational speed.
- The frequency domain compensates for system linearization by providing higher response amplitudes. This exaggeration in response yields more conservative results.

3 CONCLUSION

This research focused on determining whether response-based workability would improve the accuracy of vessel response predictions and on developing a methodology that simplified this process. Additionally, a notable achievement of this research was the creation of an integrated toolbox that consolidated all processes involved. This toolbox not only facilitated the implementation of the developed methodologies but also streamlined the overall workflow, enhancing both efficiency and usability.

The decision-making tool must not only deliver rapid results but also ensure reliability by accurately reflecting the most realistic possible responses.

Using forecasted data, sea states were analyzed over a 72-hour period. The calculation of responses for each spectrum and heading required a total of approximately 7 minutes and 57 seconds.
To provide the final results for the decision-making tool, the most probable maximum (MPM) response was calculated using 3-hour periods, as recommended by DNV. Based on these values and operational limits, the workability report was generated in just 2 minutes. Overall, the proposed methodology completed the entire workability assessment within 23 minutes and 42 seconds, covering a 72-hour period. This approach significantly enhances the efficiency of the decision-making tool.
The primary question of this research was whether implementing the response-based methodology offers improved vessel workability predictions. To address this question, the following key conclusions need to be considered:

3.1 Applicability

1. **How adaptable is the proposed methodology to various types of heavy lift vessels and offshore operations, and what are its limitations in different scenarios?**

   In this research, two different OrcaFlex models were used to validate the methodology. It can be concluded that the methodology exhibits a high level of adaptability to almost any OrcaFlex model, provided that the model is well-developed and all hydrodynamic and hydrostatic parameters are predefined.

2. **How does the linearization of the frequency domain influence the accuracy and reliability of the model's response?**

   The application of linearization in the frequency domain results in higher response amplitudes but improved phase correlation. This indicates that the frequency domain analysis tends to produce more conservative results when linearization is applied. This effect was consistently observed across different wave data inputs, with the most notable case being the responses obtained from Airy wave excitations. For responses involving significant nonlinearities, the amplitudes in the frequency domain were substantially higher.

3.2 Advantages

3. **How can the incorporation of forecasted 2D wave spectra enhance the precision of motion forecasts and better account for wave misalignments, compared to conventional spectras?**

   Methods such as JONSWAP spectrum, might overlook complex interactions and misalignments between different wave components. These models often use simplified assumptions that can lead to inaccurate assessments of sea states, either underestimating or overestimating the potential impact of waves on vessel operations. For example, traditional methods might predict too optimistic operability windows, resulting in unexpected downtimes, or they might forecast too conservative downtime, potentially missing operational opportunities.

   The 2D wave spectra offer more accurate assessments of sea states and manage the nonlinear interactions between wave components more effectively. Consequently, this approach leads to more reliable and extended workability windows by accounting for specific restrictions based on vessel headings.

4. **Is it possible for the response-based workability to overtake weather-based workability, and can the industry rely only on this approach?**

   The results of this study indicated that response-based workability could significantly differ from weather-based workability, particularly in cases where workable windows were limited to specific vessel headings or where the weather-based method suggested operational feasibility while the response-based method did not. At present, response-based workability could serve as a primary methodology for assessing workability but should be used in conjunction with the weather-based method.

   Incorporating response-based workability alongside weather-based methods could enhance both the tendering and operational phases of projects. During the tender phase, it could enable a more accurate estimation of the expected weather downtime, providing a clearer understanding of operational constraints and potential risks. In the operational phase, it could aid the crew by offering more detailed decision-making tools. For instance, while weather-based data might indicate a favorable condition, response-based analysis could reveal that even a wave system with a low significant wave height (H_s) could present critical challenges if its frequency aligns with the vessel's critical response points.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to DEME Offshore for the invaluable opportunity to conduct my thesis research. Your support and resources were crucial to the success of my project.

I am also profoundly thankful to EMSHIP+ for offering a comprehensive and challenging curriculum that greatly enriched my academic experience. My sincere appreciation extends to the University of Liège and École Centrale de Nantes for their exceptional educational environments and for allowing me to be part of such esteemed institutions.

A special thanks to my professors, Philippe Rigo and Lionel Gentaz, whose guidance, encouragement, and insightful feedback were instrumental throughout my studies. I am also deeply grateful to my thesis advisors, Sijun Rao and Benjamin Baert, for their expert advice, unwavering support, and dedication, which were pivotal in shaping the outcome of my thesis.

I also wish to express my profound appreciation to my family, especially my mother, Celibeth, and my brother, Gabriel, for their constant encouragement. Additionally, I am truly grateful to my dear friend Barbara, whose reliable support and companionship made this journey all the more rewarding.

To all my friends who joined me on this journey, your encouragement and presence have been invaluable.

Thank you all for your consistent support and confidence in my work.