Ocean Engineering 125 (2016) 308–327

Contents lists available at ScienceDirect

Ocean Engineering

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

Methodology for assessment of the operational limits and operability of marine operations

Wilson Guachamin Acero [a,b,c,*], Lin Li [a,b,c], Zhen Gao [a,b,c], Torgeir Moan [a,b,c]

[a] Department of Marine Technology, Norwegian University of Science and Technology (NTNU), Trondheim NO-7491, Norway
[b] Centre for Ships and Ocean Structures (CeSOS), NTNU, Norway
[c] Centre for Autonomous Marine Operations and Systems (AMOS), NTNU, Norway

ARTICLE INFO

Article history:
Received 9 May 2016
Received in revised form
27 July 2016
Accepted 17 August 2016
Available online 31 August 2016

Keywords:
Operational limits
Marine operations
Offshore installation
Limiting parameters
Allowable sea states
Weather windows
Operability

ABSTRACT

This paper deals with a general methodology for assessment of the operational limits and the operability of marine operations during the planning phase with emphasis on offshore wind turbine (OWT) installation activities. A systematic approach based on operational procedures and numerical analyses is used to identify critical events and corresponding response parameters. Identifying them is important for taking mitigation actions by modifying the equipment and procedures. In the proposed methodology, the operational limits are established in terms of allowable limits of sea states. In addition, the operational limits of a complete marine operation are determined by taking into account several activities, their durations, continuity, and sequential execution. This methodology is demonstrated in a case study dealing with installation of an offshore wind turbine monopile (MP) and a transition piece (TP). The developed methodology is generic and applicable to any marine operation for which operational limits need to be established and used on-board as a basis for decision-making towards safe execution of operations.

1. Introduction

Marine operations is “a generic term covering, but not limited to the following activities which are subjected to the hazards of the marine environment: Load-out / load-in, transportation / towage, lift / lowering, tow-out / tow-in, float-over / float-off, jacket launch / jacket upend, pipeline installation, construction afloat” (GL Noble Denton, 2015). This study deals with analysis of marine operations, and the required terms and definitions are provided in the appendix. These terms are shown in italics when introduced for the first time in this paper.

Marine operations are executed following a systematic *operational procedure*, which is normally developed in the planning phase based on information about the equipment and offshore site. A marine operation consists of many activities or sub-operations. During planning of the offshore activities, risk management of *critical events* that can lead to failures is required (Det Norske Veritas, 2011). It involves the identification of hazardous events and the corresponding response parameters and critical activities as well as the quantification of associated risks, and suggestions for mitigation actions. Thus, as part of the risk management, it is necessary to avoid the occurrence of critical events by establishing limits to the response parameters below which the operations can be executed in a safe manner.

Consider the installation of a topside module using an offshore crane vessel. Based on an installation procedure, qualitative risk analysis can be conducted to identify hazardous events and critical operations. Fig. 1 shows a critical offshore activity, for instance, the lift-off of a topside module from a cargo barge. A critical event is then the structural failure of a lifting wire. This event can be avoided if the total tension in the wire rope is kept below its minimum breaking load (including a safety factor that accounts for uncertainties). The tension in the wire rope can be assessed from numerical analyses. The sea states leading to a wire tension lower than the limit are the *allowable sea states* of the operation, which are the main focus of this paper.

The response parameter that describes the critical event and limits the execution of an activity, for instance the wire tension, is suitable to assess the magnitude of the loads when carrying out numerical analyses of the lift-off activity during the planning phase. This parameter (tension) can also be monitored “during” the execution of an operation, and thus, it is suitable for taking mitigation actions; however, it cannot be used as a criterion to make a decision on whether to start or not the lifting operation. This is because the decision needs to be made before the activities are

* Corresponding author at: Department of Marine Technology, Norwegian University of Science and Technology (NTNU), Trondheim NO-7491, Norway.
E-mail address: wilson.i.g.acero@ntnu.no (W. Guachamin Acero).

http://dx.doi.org/10.1016/j.oceaneng.2016.08.015
0029-8018/

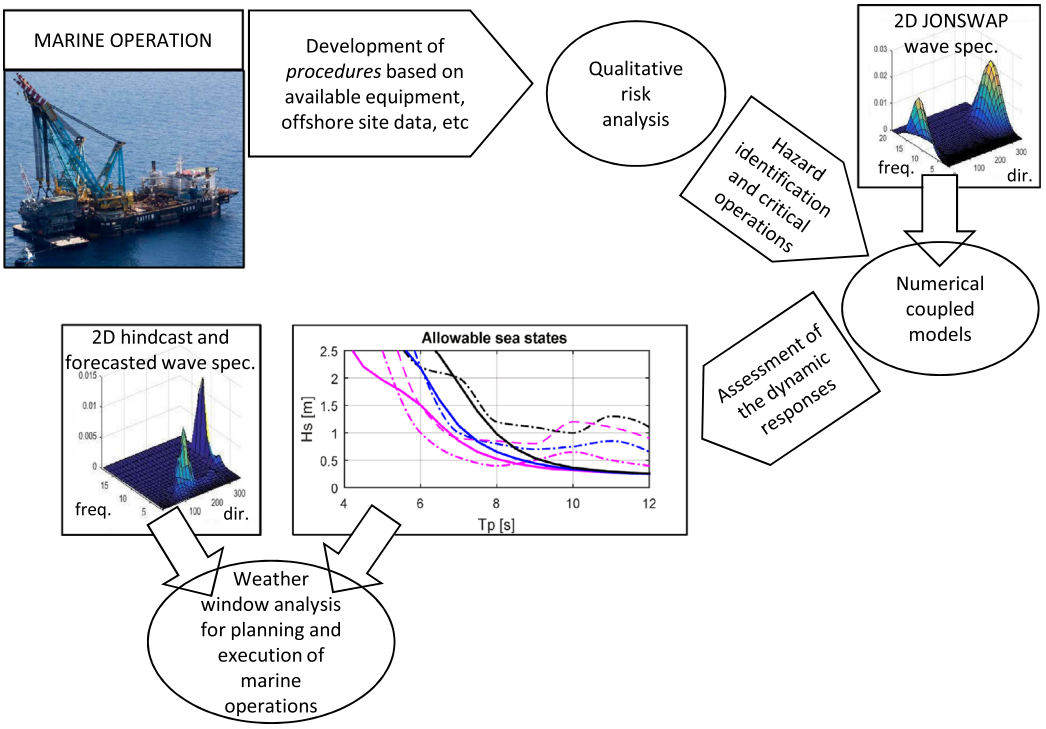

Fig. 1. Overview of a general procedure for assessment of response-based operational limits and weather window analysis of marine operations.

executed, where there is no tension to be measured.

Thus, there is a loading condition (LC) that corresponds to the *monitoring phase prior to execution* of the operations, which is useful for making decisions on whether to start or not an operation. The decision is based on vessel responses, information from wave forecasts, and *operational limits* given in the operational procedure. The operational limits are compared with the sea state parameters or measurable vessel responses and the decision is made. In particular, Det Norske Veritas (2014a) states that operational criteria such as wind speed, wave conditions, and relative motions need to be provided for the monitoring phase, and should be included in the operation manual. Therefore, the operational limits should include both, *allowable limits* of sea states and allowable limits of responses of the vessels in monitoring phases prior to execution. Note that in general the environmental parameters that need to be considered will depend on the type of operation. For instance, wind speed is important for OWT blades installation, and wind and current speed are important for towing activities.

To date, limited work has been carried out to identify critical events and establish operational limits based on structural responses, and no systematic *methodology* seems to have been published. The current practice is to set these limits in terms of allowable sea states and *allowable responses* of the vessel in the monitoring phases prior to execution based on industry experience, so the origin of these limits is not clear. Moreover, only critical phases of marine operations are studied, e.g., by carrying out model tests under "specific" sea states. This paper aims at identifying critical events and establishing response-based operational limits (in terms of sea state parameters) for marine operations, see Fig. 1. Based on the operational limits, environmental data, and assessment of various sources of uncertainties, reliability analysis of marine operations can be conducted; however, this topic is out of the scope of this paper.

A literature review on operational limits of various marine operations is provided below. Det Norske Veritas (2011), International (2015) and GL Noble Denton (2015) provide recommendations on the operational criteria for planning and execution of marine operations. Parameters such as significant wave height (*Hs*), wind and current speed, and others that may affect the system responses are recommended to be included. For weather-restricted operations, i.e. with duration less than 72 h, a design limit of the *Hs* parameter is normally considered. This parameter is reduced by alpha factors that account for uncertainties in the weather forecast methods and the reference period (duration) T_R of the activities. A study on derivation of alpha factors was carried out by Wilcken (2012). The alpha factor decreases with increasing T_R and increases with increasing *Hs* or when more reliable forecast methods are used. For instance, measurements using wave buoys or the presence of a meteorologist on site will increase the confidence of weather forecasting, so the alpha factors increase. As shown above, the design criteria for planning and execution of marine operations are mainly expressed in terms of *Hs* while the wave spectrum peak period (*Tp*) is not considered. Since floating units are highly sensitive to *Tp*, this parameter needs to be included. Moreover, the required terminology for analysis of marine operations is incomplete in the available literature.

Clauss and Riekert (1990a,b) presented a summary of operational limits in terms floating crane vessel motion responses. These limits were given based on experience from projects executed in the North Sea. Some of these vessel motion criteria were also expressed in terms of sea state parameters. Likewise, Smith et al. (1996) provided the operational limits in terms of allowable impact velocities for a jack-up vessel during the standard leg lowering procedure. The limits were derived from structural damage criteria based on structural analyses of leg members. Similarly, Clauss et al. (1998) proposed a methodology for assessment of the allowable sea states during offshore pipelaying based on maximum permissible stresses on the pipe. The methodology accounts for stresses from wave and vessel motions. In addition, Cozijn et al. (2008) assessed the operational limits for installing a