Waiting on Suitable Weather to Perform Marine Operations

Ove T. Gudmestad

Abstract The marine industry carries out a large number of marine operations worldwide. The operations are becoming more and more advanced and include deep-water installation activities and commercial transport through the Arctic ice. The probability of encountering an unwanted event during these operations is high in certain areas of the world, in particular, where reliable weather forecasts do not cover the complete duration of the operation. Det Norske Veritas (now DNVGL) has considered the statistics of the reliability of weather forecasts (performing a comparison of forecasted wave heights and actual measured waves) and suggests that the wave height criterion for starting the operation (using specific equipment) should be reduced by an "alpha factor". The alpha factor depends on location, season of the year and duration of the operation. However, in certain areas, like in the Arctic, where the weather forecasts are particularly uncertain, no alpha factors for operations exceeding a short period have been suggested. The need to wait for a suitable weather forecast (WOW) exceeding the expected period of an operation puts a lot of strain on project management as WOW is costly for the party who shall pay for the waiting. Good project management takes this into account, prioritizing safe operations higher than taking the risk of encountering unwanted events with the possibility of substantial economic loss and also the potential for unsafe operations. Examples will be given from actual operations on the Norwegian shelf, and a discussion of operations in Arctic conditions will be provided.

Keywords Design versus operations
Weather limitations for temporary operations
Influence of wave height and wave period · Reliability of weather forecasts
Alpha factor · Waiting on weather
Requirement to decisions for initiating a marine operation
Management of marine projects · Specifics for the situations in the Arctic region

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1 Introduction

1.1 Design Aspects Versus Operational Activities

International design standards are concerned with the safety of technical solutions. The load and resistance factor design method [1] specifies load and resistance factors to be applied to characteristic values for load and resistance in structural design. The ISO 19900 series of standards, for example, ensures safe design with an acceptable low probability of damage or collapse. Checking of the design for different limit states (serviceability, ultimate, fatigue and extreme) ensures that attention is paid to regular usage, continued operations in the defined ultimate condition, and avoidance of collapse in case of an extreme event situation. Damage caused by continued use is ensured through fatigue checks. It is recognized that safe operations shall be ensured for personnel, the environment and the asset. The characteristic values are normally specified in international standards; however, the ISO member countries are allowed to define "stricter" requirements, thereby reducing the probability of damage or collapse. For certain structures (like structures to be used in the oil and gas industry), high characteristic values are selected for loads. This is ensured through selecting values with low annual probability of exceedance for the load estimates. For other types of structures where damage will not have very large consequences (e.g. for structures supporting wind turbines), lesser values of the characteristic loads can be selected.

In the case of temporary activities, such as during construction work and during temporary marine activities, the owner/operator is freer to select criteria as long as they ensure safety during the specified operations. It may be prudent to wait for suitable weather conditions rather than to initiate activities under harsh conditions. It may, for example, represent large savings to hire construction vessels for well maintenance rather than to hire a large drilling rig. The reduced day rate of the construction vessel compared to that of a rig could more than compensate for periods of *waiting for suitable weather conditions to carry out the operation.* However, the equipment must be suitable for the season and be able to go on safe stand-by should harsh weather unexpectedly appear. In this paper, we will discuss aspects which shall be taken into account when making decisions regarding marine operations. A special discussion will be related to marine activities in cold climate regions.

1.2 Weather Limitations for Temporary Operations

Temporary operations are carried out as specialized operations and are not representative of day-to-day activities. Such operations could be part of construction, installation or maintenance activities. These activities should normally be performed during the good weather season, avoiding the harsh weather season when the probability of high winds or large waves is substantial. Historical weather data can normally

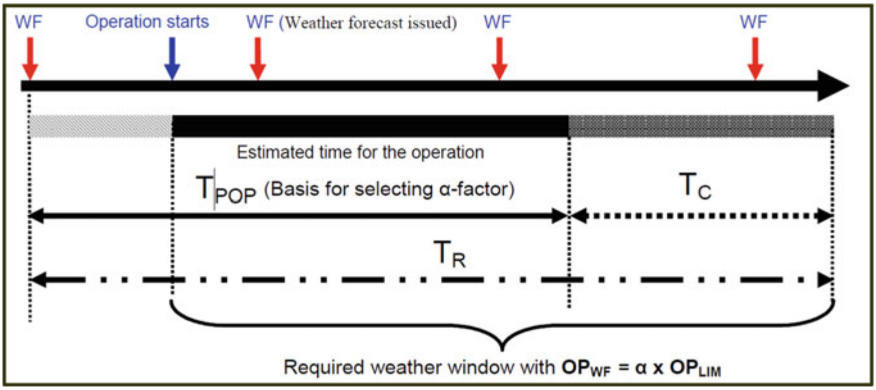

Fig. 1 From DNV [2]: Marine operations with a reference period (TR) less than 96 h and a planned operation time (TPOP) less than 72 h may normally be defined as weather-restricted. However, in areas and/or seasons where a corresponding reliable weather forecast is not considered realistic, a shorter limiting TR shall be applied

be produced for a location, from which we can calculate the probability of finding the required weather window (with limited wave condition for the duration of the planned operation). Wave data are often hind-casted from past weather maps in case actual measurements are not available. Based on such data and information about equipment capability, we can find the probability of having the work done during different seasons of the year. We will also find the expected time we will have to wait for suitable weather to perform the actual operation.

On site, the actual weather condition and weather forecast will decide whether we will be in position to start the operation. Normally, *weather-restricted operations* are operations that can be carried out within a weather window of 72 h (3 days). For operations that need more time, the seasonal 10-year expected maximum weather could apply. However, in situations with long-term reliable weather forecasts (e.g. under constant high-pressure situations) when the operator is in close contacts with meteorological centres, longer weather-restricted periods exceeding the 72 h could be considered.

For a general view of operation planning, see Fig. 1 (from DNV [2]).

2 Requirements to Temporary Marine Operations

2.1 Vessel Response Due to Wind and Waves

Vessels are responding to wind loads, and certain operations, like crane operations, are very vulnerable to the wind conditions. Lifting operations may, therefore, not be conducted during strong winds. More important is the response to waves where any vessel will respond in all six degrees of freedom. The response to waves varies very much from vessel to vessel; bilge keels will reduce heave and roll motions because of increased added mass and damping, while bulb bows will reduce the pitch motion because of increased bow buoyancy when the vessel pitches into waves. Furthermore, increased vessel size causes reduced heave motions, also because of the increased added mass. To design the most suitable vessel for certain operations is an art left for the naval architects.

The response amplitude operators (RAOs) are normally used to study the response to waves. The RAOs give the response to one-metre high waves with different periods and are found (from analysis or from wave tank experiments) for all six degrees of freedom of motions and for different angles of approach of the waves. At certain wave periods, a vessel gets into resonance with the waves and the values of the RAOs can be considerable (depending on vessel damping), amplifying the vessel's response. Resonances with large waves will thus produce considerable vessel motions. Also, resonances with long swell waves (periods typically of 15 s or more) could cause significant vessel motions and certain activities cannot be carried out during swell waves. Activities that may be halted are, for example, installation of "jackups" when heave due to swells could lead to mud-mat damage as mud-mats hit the bottom and during lifting when the crane's response be amplified by the response of the vessel; see, for example, DN [3]. In the cited case, a vessel that could not work in limited waves was contracted with the consequence that more than 75 M US $ was wasted.

The requirement to an actual marine operation is determined by the motions which can be tolerated during the operation. Based on the vessel's RAOs, we can then decide on the limited wave height/period during which the operation can be carried out for any specific vessel. It is obvious that the information about vessel's RAO is important when judging the capability of a vessel to perform a task. Some vessels may be capable of working in Hs of 4.0 m for a specific marine operation, while a competing vessel may be limited to 2.5 m. Vessel owners do therefore treat information about their vessels' RAOs as confidential information. However, for the customer, it is of importance to know:

- The vessel's RAOs during bid evaluations to determine the likely operation time (including the expected downtime) for the vessels being considered for a marine operation.

2.2 Influence of Wave Height and Wave Period

As discussed above, statistics regarding wave heights (significant wave heights, H_s) and wave periods (wave spectral shapes and spectral peak periods, T_p) are important for selection of vessel to perform a marine operation. This information is used to determine the probability of successful operations during a certain season of the year. Weather forecasters will often give the wave height, while the wave period be much more uncertain. However, knowledge about the wave period is as least as important as knowledge about the wave height. It might also be important to have information about swell waves under which the sea may appear as calm, while resonance with vessel motions may restrict the ability to work; see, for example, Olugbenga et al. [4]. Therefore, in order to select a suitable vessel for an operation, the customer provides the bidders with the following information:

- Wave height and wave period statistics for the actual season and for following months (in case of the necessity to extend a contract).
- Wave heights and swell periods during the season and following months.

Of another matter is the possibility that two wave conditions occur simultaneously: Wind waves coming from the prevailing wind direction and swell waves, potentially coming from another direction. The combination could result in severe roll motions even if the vessel is heading up against the wind waves [5]. Such situations have been recorded in the Norwegian Sea (at the Norne field at 66° north).

2.3 Reliability of Weather Forecasts

Weather conditions could deteriorate quickly and weather forecasts become more and more uncertain as time passes. A marine activity will get a "go" when the expected wave conditions during the preparation phase, the work phase and the end of work phase for an activity are within the limiting conditions for the activity. Time starts ticking when the preparation gets to a "no return to start" situation, for example, when the sea fastening is being cut during the preparation of an offshore lift operation. Normally in the North Sea area, we refer to a 72-h period as the period when weather-restricted operations can be executed. In case of stable high-pressure situations, however, the reliability of the forecasts can be very good, even exceeding the 72-h period set for weather-restricted operations. Other locations of the world would have longer periods of reliable weather forecasts, while the forecast uncertainty is even larger in the Barents Sea and in most Arctic Seas during long periods of the year.

Note that the needs to identify the uncertainty in the weather forecast do not only relate to the wave height, but also relate to the wave spectrum and in particular to the peak period of the wave spectrum. A comprehensive review of uncertainty in weather prediction is given by Bauer et al. [6].

2.4 Alpha Factor

In view of the limitations due to the weather conditions, it is of most importance to be able to estimate the uncertainty in the weather forecasts. DNV [2] has evaluated the uncertainty in the weather forecasts for certain offshore seas: "B 700–701: Uncertainty in both monitoring and forecasting of the environmental conditions shall

Table 1 Alpha factor for North Sea conditions

Table 4-1 α-factor for waves, base case							
Operational Period [h]	*Design Wave Height [m]*						
	$H_s = 1$	$1 < H_s < 2$	$H_s = 2$	$2 < H_s < 4$	$H_s = 4$	$4 < H_s < 6$	$H_s \geq 6$
$T_{POP} \leq 12$	0.65	Linear Interpolation	0.76	Linear Interpolation	0.79	Linear Interpolation	0.80
$T_{POP} \leq 24$	0.63		0.73		0.76		0.78
$T_{POP} \leq 36$	0.62		0.71		0.73		0.76
$T_{POP} \leq 48$	0.60		0.68		0.71		0.74
$T_{POP} \leq 72$	0.55		0.63		0.68		0.72

be considered. It is recommended that this is done by defining a forecasted (and, if applicable, monitored at the operation start) operational criteria—OP_{WF}, defined as:

$$OP_{WF} = \text{alpha } x \ OP_{LIM}.$$

where OP_{LIM} is the limiting operational environmental criteria".

Furthermore, it could be noted that a recommendation is given for operations that can be halted: "703: For operations that could be halted, see 506, the alpha-factor could normally be selected based on a TPOP defined as the time between weather forecasts (e.g. 12 h) plus the required time to safely cease the operation and bring the handled object into a safe condition". Table 1 (Table 4.1 from DNV [2]) gives alpha factors for different wave heights and operational periods in the North Sea. See also DNV [2] for more details in case there is a meteorologist at site, etc.

Even if the alpha factors given by DNV provide guidance on recommended wave heights for initiating a marine operation, no guidance on wave periods is given except for a general statement: "706: Special considerations should be made regarding uncertainty in the wave periods. I.e. if the operation is particularly sensitive to some wave periods (e.g. swell), also uncertainty in the forecasted wave periods shall be considered".

2.5 Waiting on Suitable Weather (WOW) to Perform Marine Operations

In case the weather condition is not suitable to initiate a marine operation, the captain of the vessel has to decide on putting the operation on hold, causing the complete marine spread to be put on hold. It shall be noted that the law of the sea gives the captain this responsibility when there is a danger to personnel, to the environment or to the ship (the asset). The costs of waiting on weather can be very large, in particular in oil- and gas-related projects where delays can lead to loss of production. The captain will be advised by his marine engineering staff as to the potential consequences of continuing the work. Furthermore, the client will normally employ a warranty surveyor to stay on board accepting any task that shall be covered by insurance.

Although the client could demand that the operations continue without insurance, the client cannot demand that the captain carries on if he decides it is unsafe to perform the task. Normally, the team of persons representing the client, the warranty surveyor and the captain will agree on when a task can be initiated and continued. An on-board meteorologist can in many situations be to good help to provide sound advice for decisions.

As most mariners have a careful attitude to work when the weather conditions deteriorate, a situation could develop where the decision to halt the work was not warranted; the weather did not deteriorate. In such situations, the client could be tempted to sue the marine operator for delaying the activity unnecessarily. Such a case is not optimal and could end up in court. However, the captain's decision is in general protected, in particular when safety to personnel, the environment and/or the vessel is in danger. A specific situation is the case when management of the operator getting involved in the decision. A high-reliability organization would not work like this. See, for example, [7]. She studied organizational processes necessary to operate safely technologically complex organizations that should not do great physical harm to themselves and their surrounding environments. There are, however, examples of near misses or actual misses in marine operation activities [8].

3 Specifics of Marine Operations in the Arctic Region

The design weather conditions in the Barents Sea are typical for the extreme conditions in the Arctic region. Orimolade et al. [9] have concluded that the estimated 100-year H_s for four locations in the Barents Sea show that the extreme wave heights in the Barents Sea in general are less harsh further north compared to the south. The general observation is in agreement with the expected spatial trends in the wave climate in the Barents Sea. Finally, a 57-year hind-cast dataset used in their study does not suggest any specific temporal trend in the historical significant wave heights at the selected Barents Sea locations.

On the other hand, the paper does not consider the weather conditions during typical marine operational conditions, although long periods of limited waves are present during the summer season, during which marine operations safely can be executed. During the fall season, however, the weather conditions become quite unpredictable as small-scale polar low pressures can develop at the ice edge. Here, cold air above the ice and warmer air above the open sea create an unstable situation that can lead to polar low pressures travelling south and eastwards (due to the Coriolis effect). For a review of polar lows, see Rasmussen and Turner [10], and see also Fig. 2.

The creation of polar lows is not well understood; however, meteorologists may give a forecasted probability of polar lows. The probability may be unrealistically high due to the uncertainty in the generating process. Furthermore, polar lows are cyclone-type weather conditions and the paths of the polar lows are very uncertain. During such conditions, there is a certain probability of a polar low, and marine operations which require several days of limited waves have to be put on hold. Even

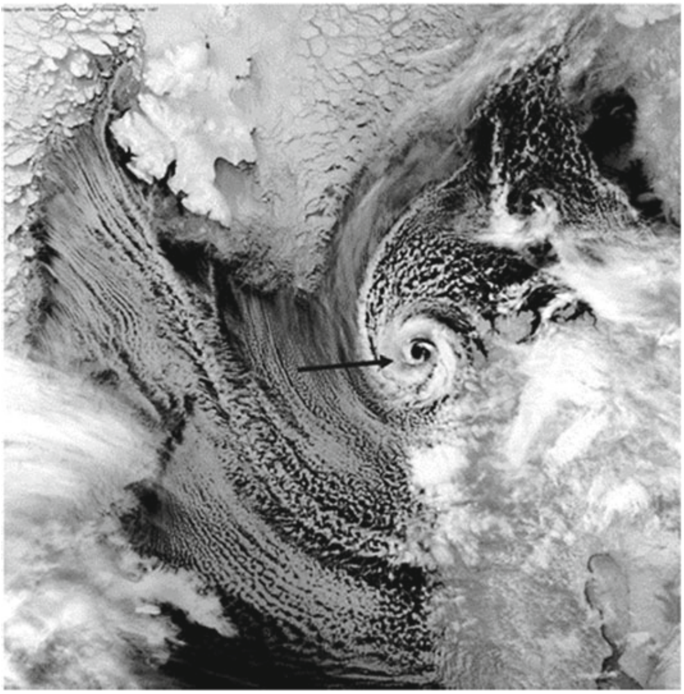

Fig. 2 A satellite image of a fully developed polar low over the Barents Sea from 0418 UTC 27 February 1987 (Courtesy Neil Lonie: NERC Satellite Receiving Station, Dundee University, Scotland, http://www.sat.dundee.ac.uk/)

if the waves in polar lows may not reach design wave conditions, the waves will reach heights exceeding the requirements of safe marine operations. Furthermore, polar lows are followed (on the backside) by large accumulations of snow or hail. Wilcken [11] has concluded that it will not be possible to suggest alpha factors for seasons of the year when polar lows may be created reaching some location where marine operations be undertaken. Under such conditions, marine operations must be very carefully reviewed together with meteorologists prior to initiating activities that may be hampered in case of polar low occurrences.

Resent research [12] has also confirmed a model suggested by Dysthe and Harbitz [13] that polar lows travelling with the phase speed of the waves can be in resonance such that the effective fetch is sufficiently long to create very large waves within few hours. In such cases also the integrity of marine vessels may be endangered. Meteorologists suggest that this resonant situation should be forecasted to prepare seafarers for situations with very large wave buildup [14].

4 Conclusions

In this paper, we have discussed the requirements to carry out safe marine operations, criteria are reviewed, and we have emphasized on the needs for forecasting the uncertainty of wave heights and the wave periods [15] throughout the period of the marine operation. At present, main emphasis is on wave heights; however, resonances between vessel characteristics (vessel RAOs) and waves with periods matching the peaks of the vessels' RAOs could lead to large response of marine vessels with the potential of failed marine operations. Also, special attention should be on forecasting swell waves being in resonance with peak periods of the vessels' RAOs.

It is, furthermore, concluded that weather conditions in Arctic regions during seasons when polar low pressures can occur are particularly uncertain, and that marine operations cannot be conducted during forecasting of potential polar low pressures.

Finally, we present a conclusion that high-reliability companies are very aware of the potential of severe conditions during marine operations, respecting the advice of meteorologists and decisions of their captains.

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