DNV

STANDARD

DNV-ST-0111 Edition December 2021

Assessment of station keeping capability of dynamic positioning vessels

DNV AS

FOREWORD

DNV standards contain requirements, principles and acceptance criteria for objects, personnel, organisations and/or operations.

Any comments may be sent by e-mail to *rules@dnv.com*

CHANGES – CURRENT

This document supersedes the March 2018 edition of DNVGL-ST-0111.
The numbering and/or title of items containing changes is highlighted in red.

Changes December 2021

Topic	*Reference*	*Description*
Scope	[1.3]	Added a guidance note to inform about the accuracy of results in relation to the DP capability assessments.
Definitions	[1.3]	Updated the definition of DP capability level 2-site and level 3-site. Added specific load condition which was missing.
	[2.4.6]	Improved the definition of thruster utilization (total effective thrust, the word maximum was missing for the nominal thrust).
	[3.3.3]	Added the definition of wave directional spreading.
	[3.8.2]	Added the definition of the coordinate system for the actuator angle.
	[3.11.5]	Improved the definition of the angle alpha flush.
	[3.12.4], [3.12.5]	Added clarification that for level 1, the electrical losses are included in the 10% of reserved power.
	[4.3.2]	Added a note that for semi-submersibles wave forces may be affected by the current speed.
	[5.1]	Added a note that the vessel draught is not required to be the summer load line draught.
	[5.4]	Clarified wind speed reference height at 10 m above sea level.
References	Table 1-2	Added reference to IMO MSC.1/Circ. 1580 *Guidelines for vessels and units with dynamic positioning (DP) systems*.
Documentation	Table 2-3	Inclusion of other power sources, different fuels, and minimum time requirement.
Methodology for the calculation for DP Capability assessments	[3.9.2]	Added the mechanical efficiency for permanent magnet cycloidal actuators. Clarified the naming of rim-driven for the permanent magnet actuators.
	[3.9.4]	The actuator ventilation loss formulation is completely changed. The previous formulation was valid for level 1 (summer load line draught) only and did not account for the propeller load. The new formulation is valid also for propeller closer to the sea surface, for example for ballast conditions.
	Table 3-4	Updated the mechanical efficiency for non-cycloidal permanent magnet actuators.
Additional rules for battery usage	[3.12.2]	Added a rule for the use of batteries when included in the level 1 calculation.
	[4.11.2]	Added a rule for the use of batteries when included in the level 2 calculation.

Topic	*Reference*	*Description*
Verification requirements	[4.2.2]	Removed the requirement for running level 1 and level 2 when running level 2.
	[5.2.2]	Removed the requirement for running level 1 and level 2 when running level 2-site.
	[6.2.1]	Removed the requirement to run level 1 analysis when running level 3 analyses.
	[7.2.1]	Removed the requirement to run level 1 analysis when running level 3-site analyses.
	App.B	Removed former appendix B as the requirement for comparison of DP capability levels is removed.
Requirements for how to handle power	[5.12.1]	Updated the power requirements for level 2-site such as they are the same as level 2.
	[6.17.4]	Updated the level 3 power requirements when using batteries to be the same as for level 1.
Wind spectrum for level 3	[6.7.3]	Requirements for the wind spectrum for level 3 analyses were added.
Requirements for reporting	[7.5]	Added wind spectrum and profile, current speed profile to be documented when running level 3-site analyses.
	[A.2.3]	Specified that the coordinate systems in the report shall be the same as the one required for the DP capability assessment.
	Table A-2	Replaced design draught with summer load line draught as this is the requirement for level 1.
	[A.4]	Removed requirements for running the level 1 and level 2 analyses when reporting level 2 analyses.
	[A.5]	Updated the reporting requirements for level 2-site to reflect the changes in the requirements for the level 2-site analyses.
	[A.6]	Updated the reporting requirements for level 3 to reflect the changes in the requirements for the level 3 analyses.
	[A.7]	Updated the reporting requirements for level 3-site to reflect the changes in the requirements for the level 3-site analyses.
Additional guidance for writing specifications	App.B	Added a guidance section for helping the users to write specifications when requiring analyses based on this document.
Rebranding to DNV	All	This document has been revised due to the rebranding of DNV GL to DNV. The following have been updated: the company name, material and certificate designations, and references to other documents in the DNV portfolio. Some of the documents referred to may not yet have been rebranded. If so, please see the relevant DNV GL document.

Editorial corrections

In addition to the above stated changes, editorial corrections may have been made.

CONTENTS

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SECTION 1 GENERAL

1.1 Introduction

Reliable documentation of a vessel's position and heading keeping capabilities is vital for planning and execution of safe and reliable operations with dynamic positioning (DP) vessels. The vessel's station keeping capabilities should be clearly understood, both with respect to the intact vessel condition, and for redundant DP vessels even more important also in case the vessels capability should be degraded during operations. E.g. due to relevant failures associated with the vessels dynamic positioning class notation.

1.2 Objective

The objective with this standard is to set clear and consistent requirements for DP station keeping capability assessment. The standard includes three different levels for assessing the DP station keeping performance. DP capability level 1 numbers shall be calculated based on a prescriptive static method so that results calculated for different vessels will be fully consistent and comparable. To support this objective the standard also sets unambiguous requirements for documentation of the calculations and how the results shall be presented. DP capability level 2 sets requirements for the assessment of the DP station keeping capability based on a more comprehensive quasi-static method which allows for more flexibility and project specific adjustments compared to the DP capability level 1 method. In addition the standard provides requirements for DP capability level 3 where the DP station keeping capability can be computed based on time-domain simulations.

1.3 Scope

This standard sets requirements for calculation and documentation of DP station keeping capability at three different levels:

— *DP capability level 1*: this level sets requirements to a basic and prescriptive static method for documenting DP capability numbers for ship-shaped-mono-hull vessels. The calculations shall be based on a static balance of environmental forces and the vessel's actuator forces. The calculations shall for benchmarking purposes be based on the same specified environmental data for all vessels as specified in Table 2-3 of this standard. The rigidness of the method ensures that the DP capability numbers calculated according to the method shall be comparable between different vessels. The results are documented by DP capability numbers and capability plots.

Guidance note:

In case assessment based on different environmental data than specified in Table 2-1 is wanted, then a DP capability level 2-site calculation may be performed using the DP capability level 1 prescriptive calculation method, as long as this is applicable to the specified environment. Note that in such a case the results cannot be expressed in terms of DP capability numbers as these only relate to the environment specified in Table 2-1.

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— *DP capability level 2*: this level sets requirements for a more comprehensive quasi-static method and may be applied to all vessel shapes. This level allows for vessel specific adjustments to the calculations. Any vessel specific data shall be documented and justified. The calculations shall be based on a static balance of environmental forces and the vessel's actuator forces, and shall be based on the same specified environmental data as for level 1. The results are documented by DP capability numbers and capability plots.

— *DP capability level 2-site*: same as level 2 and in addition the method allows for the use of site specific environmental data, operation specific vessel load condition, and/or inclusion of external forces. Results will only be fully comparable between vessels in case the same calculation method and environment are used for the vessels to be compared. The results are documented by capability plots.

— *DP capability level 3*: this level sets requirements for use of time-domain simulations and may be applied to all vessel shapes. Such simulations may e.g. be used in projects where more information about the vessel dynamic capabilities is wanted. Environmental data specified for level 1 shall be used. The results are documented by DP capability numbers and capability plots.

— *DP capability level 3-site*: same as level 3 and in addition the method allows for the use of site specific environmental data, operation specific vessel load condition, and/or inclusion of external forces. Results will only be fully comparable between vessels in case the same calculation method and environment are used for the vessels to be compared. The results are documented by capability plots.

In addition to the calculation methods, this standard sets requirements for how to document the calculations and how the results shall be presented. DP capability level 1, level 2 and level 3 results shall be presented in the form of DP capability numbers assigned as specified in Table 2-1 and capability plots. DP capability level 2-site and level 3-site results shall be presented in the form of capability plots showing the limiting wind envelopes based on the site specific environmental data. Reporting shall be performed according to App.A.

Guidance note:

When calculating and evaluating DP capability assessments it should be understood that models, calculation methods, and environment specifications inherently include some inaccuracies and uncertainties. Level 1 provides generic and prescriptive methods and results. In general, when more project or operational specific information is required in such assessments, this can be achieved by applying Level 2/Level 2-site or level 3/level 3-site methods. App.B provides guidance on usage and specification of DP capability assessments according to this standard.

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1.4 Application

This standard is intended for calculation of station keeping capability of vessels with dynamic positioning systems.

1.5 Structure

This standard is structured in the following sections:

Sec.1: provides general information including objective and document structure.

Sec.2: provides general requirements applicable for all three levels of station keeping assessment.

Sec.3: describes the prescriptive method for documenting DP capability level 1 numbers for ship-shaped mono-hull vessels based on a fixed set of static formulas. The calculations shall be based on the environmental data specified in Table 2-1.

Sec.4: provides requirements for documenting DP capability level 2 numbers based on a more open quasi-static method compared to the prescriptive method in level 1. This level allows for project specific adjustments to be made and may also be applied when calculating DP capability numbers for vessels with other hull shapes than ship-shaped mono-hulls. The calculations shall be based on the environmental data specified in Table 2-1.

Sec.5: provides requirements for documenting DP capability level 2-site specific plots. The method is based on DP capability level 2 and in addition allows for the use of site specific environmental data, operation specific vessel load condition, and/or inclusion of external forces.

Sec.6: provides requirements on how to document DP capability level 3 numbers by use of time-domain simulations. The calculations shall be based on the environmental data specified in Table 2-1.

Sec.7: provides requirements on how to document DP capability level 3-site specific plots by use of time-domain simulations. The method is based on DP capability level 3 and in addition allows for the use of site specific environmental data, operation specific vessel load condition, and/or inclusion of external forces.

App.A: provides requirements for reporting and examples on how results shall be documented.

1.6 References

1.6.1

Table 1-1 lists DNV references used in this document.

Table 1-1 DNV references

Document code	*Title*
DNV-RU-SHIP Pt.6 Ch.3	Navigation, maneuvering and position keeping
DNV-RP-C205	Environmental conditions and environmental loads
DNV-RP-D102	Failure mode and effect analysis of redundant systems
DNV-RP-E306	Dynamic positioning vessel design philosophy guidelines
DNV-RP-E307	Dynamic positioning systems – operation guidance
DNV-RP-F205	Global performance analysis of deepwater floating structures

Table 1-2 lists other references used in this document.

Table 1-2 Other references

Document code	*Title*
Blendermann's method	Blendermann W., Wind Loading of Ships – Collected Data from Wind Tunnel Tests in Uniform Flow, Institut fur Schiffbau der Universitat Hamburg; 1996 December. and/or Brix J., Manoeuvring technical manual, Seehafen Verlag, 1992.
Isherwood's method	R.M. Isherwood, Wind resistance of merchant ships, Trans. of Royal Institute of Naval Architects 114, pp. 327-338 (1972)
IMO MSC/Circ.645	Guidelines for vessels with dynamic positioning systems
IMO MSC.1/Circ. 1580	Guidelines for vessels and units with dynamic positioning (DP) systems

1.6.2

A web based application for calculation of DP capability may be found at www.veracity.com. The application is based on this standard and may be used to calculate and document DP capability level 1, level 2 and level 2-site, in the form of DP capability numbers and plots. Reports obtained by use of the application may be submitted to DNV for verification.

The verbal forms defined in Table 1-3 are used in this document.

Table 1-3 Definition of verbal forms

Term	*Definition*
shall	verbal form used to indicate requirements strictly to be followed in order to conform to the document

Term	*Definition*
should	verbal form used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others
may	verbal form used to indicate a course of action permissible within the limits of the document

The terms defined in Table 1-4 are used in this document.

Table 1-4 Definitions of terms

Term	*Definition*
actuator	device generating force that can be utilized for position keeping of the vessel This also includes rudders.
available power	total installed power in the dynamic positioning system
Beaufort scale	Beaufort wind scale is an empirical measure that relates wind speed to observed conditions at sea or on land, see Table 2-1
BF number	Beaufort number as defined by the Beaufort wind scale
brake power, P_B	MCR brake power available in DP mode/bollard pull, i.e. taking power and torque limitations etc. into account
directional wave spectrum	provides the distribution of wave elevation variance as a function of both wave frequency and wave direction
DP capability numbers	see [2.2.2]
DP control system filter	filter providing the low frequency estimates of the vessel heading, position and velocity in surge, sway and yaw degrees of freedom A filter typically weights the measurements from the position reference systems and sensors based on noise levels and other criteria.
dynamic factor	the dynamic factor can be used to account for time varying dynamics
electrical power	total installed electrical power generation supplying the main electrical components in the DP system
external forces	forces acting on the vessel which is not directly caused by wind, waves, current or actuators This may e.g. be forces from pipe-laying, drilling risers or mooring lines.
force RAOs	force response amplitude per unit wave amplitude as function of wave frequency Relationship between wave surface elevation amplitude at a reference location and the vessel force response amplitude, and the phase lag between the two.
footprint	DP footprint plots are actual measurements of the vessel's DP station keeping performance in the actual environmental conditions and actuator configuration at the time the plot was taken
low frequency motion (LF)	filtered, low-frequency motion, due to actuator, wave drift, wind and current forces This is the motion that the DP control system typically aims to control.
L_{pp}	length between perpendiculars, for ship shaped vessels from centre of rudder stock (or equivalent) to the waterline when moving down the stem at summer load line, for non ship shaped maximum length of underwater hull

Term	*Definition*
minimum time requirement	minimum required time duration for which the residual remaining capacity as defined by the worst case failure design intent shall be available **Guidance note:** The time requirement will normally be governed by the maximum time necessary to safely terminate the on-going operations after the worst case single failure, given the residual remaining capacity. All relevant operational scenarios which the vessel performs and/or participates in should be considered when determining the time requirements. This time requirement should be fulfilled by the design, and the way the vessel is technically configured (technical system configuration) and operated. In addition to the actual time necessary to terminate the operation, the minimum time requirement includes also the time necessary for detection and alarming by the system, and the time needed for the operator(s) to notice, make the appropriate decision(s), and initiate the termination process. ---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
motion RAOs	motion response amplitude per unit wave amplitude as function of wave frequency Relationship between wave surface elevation amplitude at a reference location and the vessel motion response amplitude, and the phase lag between the two.
positioning limits	size of maximum acceptable footprint including both position and heading
prime mover	typically a diesel engine driving a generator or propeller
propeller aeration	phenomenon occurring when the propeller is closed to (or piercing) the water surface It is the result of air or exhaust gases being pulled into the propeller blades, and results in a large thrust loss.
propeller ventilation	same as propeller aeration
station keeping	automatically maintaining a vessel position and heading within required positioning limits
swell	see wind-generated waves
thrust allocation algorithm	algorithm which calculates the commanded thrust and angle (if applicable) to actuators from the control forces in surge, sway and yaw calculated by the station keeping controller
Tp	peak wave period, *Tp*, is the wave period with the highest energy
wave drift and QTF	the wave drift loads are defined as second order wave loads that act on objects subject to waves They may be calculated based on the dimensional quadratic transfer function (QTF). The quadratic transfer function is the transfer function that generates the slowly varying wave drift forces from a pair of waves. Given a number of wave components, the wave drift is computed from each wave pair by considering the difference frequency. The contribution from a given pair of wave components has frequency equal to the difference between the frequencies of the wave components in the pair. Wave component pairs of equal frequencies, such as each wave component paired with itself, give constant contributions (zero frequency) to the mean wave drift load. Wave component pairs that are near each other in frequency give low frequency load contributions; these determine the slowly varying part of the wave drift load, which can excite slow drift motion of the vessel. Wave component pairs that differ more in frequency give higher frequency contributions; these are generally less important to model.
wave frequent wave excitation forces	the sum of the Froude-Kriloff force and the diffraction force The Froude-Kriloff forces is the force from the undisturbed pressure in the incoming wave. The diffraction force is the remaining part of the wave excitation force (due to the presence of the body in the wave field).

Term	Definition
wave-frequency motion (WF)	the harmonic motion due to first-order wave loads, oscillating about the low-frequency vessel motion
wave realization	the wave elevation observed in the oceans changes randomly in time and it is not repeatable in time and space Theory has shown that waves in deep water can be modelled as Gaussian random processes. This means that waves with the same stochastic description will produce different wave elevations in time. As the statistical parameters of the ocean changes much more slowly than the wave elevation it may be assumed that the wave elevation process is stationary over a short time, typically taken to be three hours. Non-repeating 3-hour wave elevation time-series can be defined as wave realizations.
wind-generated waves	the wave conditions in a sea state can be divided into two classes: wind- generated (wind seas) and swell Wind seas are generated by local wind, while swell has no relationship to the local wind. Swells are waves that have travelled out of the areas where they were generated. Note that several swell components may be present at a given location.

The abbreviations described in Table 1-5 are used in this document.

Table 1-5 Abbreviations

Abbreviation	*Description*
BOL	beginning of life
CFD	computational fluid dynamic including strip theory and potential-diffraction theory
DP	dynamic positioning
DPS	DNV dynamic positioning system class notation in line with minimum requirements in IMO guidelines for vessels with dynamic positioning systems
DYNPOS	DNV dynamic positioning system class notation with additional requirements to achieve higher availability and robustness
EOL	end of life
FMEA	failure mode and effect analysis
GA	general arrangement
MCR	maximum continuous rating
MSC/Circ.	International Maritime Organisation (IMO) Marine Safety Committee Circular
NA	not applicable
OS	offshore standard
PMS	power management system
RP	recommended practice
SWBD	switchboard
WCSF	worst case single failure: refers to failure modes which, after a failure, result in the largest reduction of the position and/or heading keeping capacity This means loss of the most significant redundancy group, given the prevailing operation.

Abbreviation	*Description*
WCFDI	worst case single failure design intent: refers to the minimum remaining capacity after any relevant single failure or common cause (for a given operational mode).

SECTION 2 GENERAL CONCEPT DESCRIPTION

2.1 Applicability

2.1.1

The requirements given in this section apply to all DP capability levels.

2.1.2

The different DP capability levels may be applied to the following vessel shapes:

— DP capability level 1: ship-shaped mono-hull vessels.
— DP capability level 2, level 2-site, level 3 and level 3-site: all vessel shapes.

2.2 DP capability numbers for level 1, level 2 and level 3

2.2.1

The DP capability numbers for DP capability level 1, level 2 and level 3 shall be based on numbers correlating with the Beaufort scale as illustrated in Table 2-1.

Table 2-1 DP capability numbers and Beaufort scale wind, wave height, wave period and current speed.

Beaufort (BF) number	*DP capability number*	*Beaufort description*	*Wind speed*) [m/s]*	*Significant wave height [m]*	*Peak wave period [s]*	*Current speed [m/s]*
0	0	Calm	0	0	NA	0
1	1	Light air	1.5	0.1	3.5	0.25
2	2	Light breeze	3.4	0.4	4.5	0.50
3	3	Gentle breeze	5.4	0.8	5.5	0.75
4	4	Moderate breeze	7.9	1.3	6.5	0.75
5	5	Fresh breeze	10.7	2.1	7.5	0.75
6	6	Strong breeze	13.8	3.1	8.5	0.75
7	7	Moderate gale	17.1	4.2	9.0	0.75
8	8	Gale	20.7	5.7	10.0	0.75
9	9	Strong gale	24.4	7.4	10.5	0.75
10	10	Storm	28.4	9.5	11.5	0.75
11	11	Violent storm	32.6	12.1	12.0	0.75
12	NA	Hurricane force	NA	NA	NA	NA

*) The wind speed is the upper limit of the mean wind speed 10 m above sea level for the given DP capability number. The given peak wave periods represent the 95% confidence interval found from the world wide scatter diagram.

2.2.2

The DP capability number indicates that a vessel's position keeping ability can be maintained in the corresponding DP capability number condition and all conditions below, but not in the conditions specified for the next DP capability number.

2.3 Environmental conditions for level 2-site and level 3-site

For site specific calculations the report shall specify the site specific environmental conditions that the calculations are based on. The site specific environmental conditions shall be specified as given in Table A-11.

2.4 Capability plots

2.4.1

The results of the calculations shall be presented in the form of DP capability numbers and/or in capability plots as outlined in this standard. The capability plots shall be produced in polar form.

2.4.2

For DP capability level 1, level 2 and level 3, the capability plots showing the DP capability numbers shall be presented. In addition, also the capability plots showing the limiting wind speed, in m/s, shall be provided.

2.4.3

For DP capability level 2-site and level 3-site, as minimum, the capability plots showing the limiting wind speed in m/s shall be provided.

2.4.4

For DP capability level 1, level 2 and level 2-site there shall at the same time be a balance of forces and a balance of moments, i.e. including forces and moments generated by the actuators and forces and moments caused by environmental forces and external forces, when relevant. The calculations shall start by balancing the lowest environmental conditions and continue by balancing increasing weather conditions until the first limiting condition is reached.

2.4.5

For DP capability level 3 and DP capability level 3-site, the vessel shall be considered being able to maintain station keeping in the specified environmental conditions if positioning limits are not exceeded over the required simulated time window, see [6.3.4] and [7.3.2].

2.4.6

Results shall be presented with a minimum resolution of 10 degrees for the full 360 degree envelope. For visualization purposes linear interpolation between these points is acceptable.

Guidance note:

Capability plots based on thrust and power utilization may also be produced, but cannot replace the requirements for DP capability numbers and wind envelope plots.

Thrust utilization plots and tables may present, for each heading, e.g.:

— Thruster utilization for each actuator: the calculated thrust before losses and interactions as percentage of the actuator maximum nominal thrust in DP.
— Effective thrust for each actuator: the effective thrust (after losses and interactions) as percentage of the actuator maximum nominal thrust.
— Total thruster utilization: the sum of the magnitudes of individual actuator forces before losses and interactions (for all active actuators) as percentage of the sum of the magnitudes of maximum nominal thrust of all active actuators.
— Total effective thrust (as sum of the magnitudes of thrust after losses and interactions for all active actuators) as percentage of the sum of the magnitudes of maximum nominal thrust for each active actuator.

The data may also be shown in Newton.

Power utilization plots and tables may present, for each heading, e.g.:

— Power utilization for each actuator: the power utilized as percentage of the actuator maximum nominal power (max power in DP).
— Total power utilization from the thrusters: the sum of the used power of all active actuators as percentage of the sum of each active actuator maximum nominal power.

The data may also be shown in Watt.

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2.4.7

When presenting the result for the WCSF condition(s), an amalgamated plot shall be provided with the lowest result for each heading across all the redundancy groups.

Guidance note:

The amalgamated plot represents the vessel capability in all directions and may therefore in many cases represent several different failure conditions, as the WCSF typically will be heading dependent. An example can be found in App.A.

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2.4.8

The following plots shall be produced and presented in the report:

— vessel in its intact condition (no failures)
— a combined plot with the lowest result for each heading across all the redundancy groups
— capability plots representing failure of each redundancy group (as appendices).

The redundancy groups assumed for the DP capability calculations shall be consistent with the redundancy concept determined by the DP FMEA.

Guidance note:

In case the results of the DP FMEA do not exist at the time of calculation the assumed redundancy groups should be verified with the FMEA when available.

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2.4.9

The capability plots shall be based upon available power and the thrust output that is under control and available to the DP system, in the specified operating mode, see [3.11].

In case capability assessment is wanted for specific operational modes, these shall be specified and documented according to the requirements for the relevant DP capability level(s).

Guidance note:

If not otherwise specified the calculations may be based on the vessel being in its most efficient DP mode, e.g. no deck cargo, self elevating legs in elevated position, all deck equipment in parked position, etc.

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2.5 DP capability numbers format for level 1, 2 and 3

2.5.1

The DP capability numbers for DP capability level 1, DP capability level 2 and DP capability level 3 shall be based on the calculated capability plots and shall be presented in the following manner *DP capability-LX(A, B, C, D)*, consisting of the following information elements:

— X = 1, 2 or 3 describing the DP capability level.
— A = the smallest DP capability number (as defined in Table 2-1 and [2.2.2]) within heading ±30° relative to the environmental forces where the vessel, in its intact condition (no failures), can maintain station keeping.
— B = the smallest DP capability number (as defined in Table 2-1 and [2.2.2]) within heading 0-360° relative to the environmental forces where the vessel, in its intact condition (no failures), can maintain station keeping.
— C = the smallest DP capability number (as defined in Table 2-1 and [2.2.2]) within heading ±30° relative to the environmental forces where the vessel, in its worst case single failure condition relevant for the class notation, can maintain station keeping.
— D = the smallest DP capability number (as defined in Table 2-1 and [2.2.2]) within heading 0-360° relative to the environmental forces where the vessel, in its worst case single failure condition relevant for the class notation, can maintain station keeping.

2.5.2

The C and D parameters are not applicable for non-redundant DP systems (i.e. vessels not having their redundancy verified by issuance of a redundant DP class notation), and shall be indicated as NA (not applicable) for such vessels.

2.5.3

The information elements A, B, C and D shall be extracted from capability plots calculated in the specified conditions and according to the requirements given for the specified DP capability level, see App.A.

2.5.4

In order to determine the worst case single failure condition which the information elements C and D shall be based on, capability plots representing failure of each redundancy group (as determined by the vessel DP FMEA) shall be calculated. C and D numbers shall be the lowest numbers obtained across all the redundancy group cases.

2.5.5

The capability result for level 2-site and level 3-site shall not be presented in the form of numbers, but shall be presented in the form of capability plots showing the limiting wind speed calculated in the specified conditions and according to the requirements given for the specified DP capability level X-site.

2.6 Summary of DP capability levels

Table 2-2 provides a summary and comparison table for the main features of the different DP capability levels.

Table 2-2 Summary of the main features of the different DP capability levels.

Item	*Level 1*	*Level 2*	*Level 2-site*	*Level 3*	*Level 3-site*
Type of analysis	Quasi-static	Quasi-static	Quasi-static	Time-domain	Time-domain
DP capability calculated by	Balance of forces and moments	Same as level 1	Same as level 1	Evaluation of position and heading	Same as level 3
Calculation method	Prescriptive	Same as level 1 and allows for vessel specific adjustment	Same as level 2	Vessel specific	Vessel specific
Vessel shape	Mono-hull	All vessel shapes	All vessel shapes	All vessel shapes	All vessel shapes
Environmental conditions	DP capability number scale, collinear directions	Same as level 1	Site specific	Same as level 1	Site specific
Dynamic factor	1.25	Free to choose	Free to choose	NA	NA
Positioning limits	NA	NA	NA	5 m position, ±3 degrees heading	Site specific
Vessel motion considered	NA	NA	NA	Low frequency vessel motion	Site specific: low frequency or total vessel motion
Simulation time-window/ wave realizations	NA	NA	NA	3 hours/ min 3 realizations	At least 3-hours / min 3 realizations
Load condition (draught)	Summer load line draught	Same as level 1**)	Site specific	Same as level 1**)	Site specific
Water depth	Infinite	Infinite	Site specific	Infinite	Site specific
External forces	Not included	Not included	Site specific	Not included	Site specific
Additional computation for comparison	NA	level 1 when applicable*)	level 1 and level 2 when applicable*)	level 1 when applicable*)	level 1 when applicable*)
Required presentation of result	DP capability numbers and plots	DP capability numbers and plots	Wind envelope plots	DP capability numbers and plots	Wind envelope plots

*) DP capability level 1 cannot be computed, for example, for semi-submersible, catamaran and with vessels equipped with actuators not included in DP capability level 1. For level 2-site, the computation of level 2 is not required if DP capability level 1 cannot be computed.

**) For vessels without a defined summer load line draft, the draft shall be the deepest approved operating draft.

2.7 Documentation

The typical documentation input for DP capability calculations is given in Table 2-3. When verification of DP capability reports and results are requested, the listed documentation shall be submitted in addition to the DP capability report.

Table 2-3 DP capability input documentation.

Object	*Documentation type*	*Additional description*	*DP capability level*
Dynamic positioning system	Z050 – DP Design philosophy	The document shall describe the main features of the design and identify the redundancy and separation (when relevant) design intent, as a minimum with respect to: — actuators (thrusters, propellers and rudders, etc.) — engines and generators and other power sources — main switchboard arrangement including bus-tie(s) — type(s) of fuels. The worst case failure design intent shall also be stated. The intended minimum time requirement shall be stated. In addition the document shall specify the intended technical system configuration(s) during DP operation, as a minimum for the above listed components.	All
Vessel	Z010 – General arrangement plan	Shall show the vessel and all mounted equipment in the position assumed in the calculations.	All
Vessel	Z030 – Arrangement plan	Forbidden zones drawing or table, before and after WCSF.	All
Power system	E010 – Overall single line diagram	For DP system based on electrical power system layout with identification of all generators, transformers, switchboards, actuator frequency converters, actuator motors. Indication of rating of generators and the major consumers (kVA/kW).	All
Power system	E040 – Electrical power consumption balance	A document stating the calculated design values for power consumption and available power for the specified operational modes. Tripping of non-important consumers shall be identified in the calculation.	All
Vessel	Z100 – Specification	Vessel data as specified in App.A.	All
Actuator system	Z100 – Specification	Actuator data as specified in App.A.	All
Environmental data	Z260 – Report	Similar format as Table 2-1 and Table A-11.	All

Guidance note:

Generic definitions of the documentation types may be found in rules for classification: Ships, DNV-CG-0550 Sec.5.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

2.8 DP capability report

2.8.1

The DP capability results shall be delivered in the form of a DP capability report. The report shall follow the relevant report template as given in App.A

2.8.2

Everything but the environmental directions shall be given in a right handed coordinate system with x pointing forward, y pointing to port and z upwards. For the vessels, the origin shall be at $L_{pp}/2$, center line, and keel. Environmental directions shall be coming from directions clockwise. I.e. 0 deg is head seas and 90 deg is on starboard side.

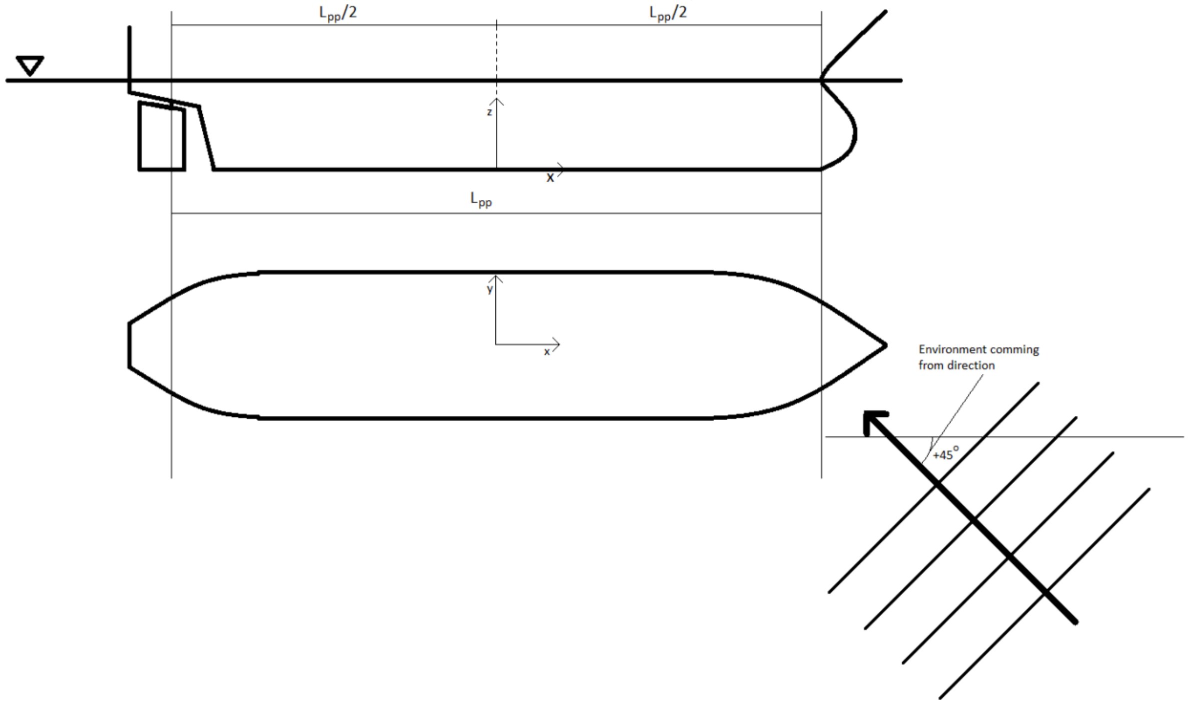

Figure 2-1 Vessel coordinate system and environmental directions

Guidance note:

Forces are positive pushing the vessel forward in surge direction, to port in sway direction and counter-clockwise in yaw direction. Force directions are 0 degrees pushing forward and 90 degrees pushing to port.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

2.8.3

SI units shall be used. Directions shall be given in degrees when reporting.

Guidance note:

Please note that the formulas in this document use radians unless otherwise stated.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

2.9 Verification

2.9.1

The verifier shall make a statement about his/her general opinion about the submitted DP capability report. Any observations regarding the quality or applicability of e.g. inputs, methodology, results and conclusions shall be stated.

Guidance note:

The DP capability report and results may be verified by the DNV on request. Such verification will be documented by issuance of a verification letter stating the conclusions of the verification.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

2.9.2

The verifier shall as a minimum check the following items:

For DP capability level 1:

— verify all input data
— verify vessel power consumption balance for the calculations
— for redundant systems verify that the specified redundancy grouping is consistent with the verified vessel FMEA. If the FMEA report has not been prepared and verified, the redundancy design intent shall be used
— perform independent calculations to verify all results
— verify that the report is provided according to the requirements for reporting.

For DP capability level 2 and DP capability level 2-site:

— verify all input data
— verify vessel power consumption balance for the calculations
— for redundant systems verify that the specified redundancy grouping is consistent with the verified vessel FMEA. If the FMEA report has not been prepared and verified, the redundancy design intent shall be used
— verify that the report is provided according to the requirements for reporting
— verify the performance for one heading resulting in each of the DP capability numbers B and D for DP capability level 2. For DP capability level 2-site, the performance may be verified for the limiting DP capability wind speeds for the heading and vessel conditions as defined for the B and D numbers
— verify performance for at least one other heading, chosen by the verifier, at DP capability level 2 or DP capability level 2-site in intact condition
— verify performance for at least one other heading, chosen by the verifier, at DP capability level 2 or DP capability level 2-site WCSF condition
— verify the results by comparing the environmental loads and the actuator forces from DP capability level 2, level 2-site and level 1, when applicable. This may be verified for the environmental conditions corresponding to the DP capability numbers B and D for DP capability level 1
— comment on the applied dynamic factors and/or thrust/power reduction.

Verification of performance as required above shall as a minimum include:

— own calculations of environmental forces and thruster forces by applying methods of similar or increased accuracy compared to methods applied in original calculation. If model test data is submitted for any forces, verifier is not required to do own calculations, but shall assess the plausibility of the model test results

— verifier shall present a comparison of all forces in the original report and own calculations. The force balance shall be verified.

In addition for DP capability level 2-site:

— comment on the specified environment, i.e. make considerations whether the specifications seem benign or harsh, e.g. in relation to a specified operating area.

For DP capability level 3 and DP capability level 3-site:

— verify all input data
— verify vessel power consumption balance for the calculations
— for redundant systems verify that the specified redundancy grouping is consistent with the verified vessel FMEA. If the FMEA report has not been prepared and verified, the redundancy design intent shall be used
— review and consider the results of the required simulator performance tests
— verify that the report is provided according to the requirements for reporting.

In addition for DP capability level 3-site:

— comment on the specified environment, i.e. make considerations whether the specifications seems benign or harsh, e.g. in relation to a specified operating area
— comment on the specified positioning criteria, simulated time, and other project specific parameters.

Guidance note:

Verifier should pay particular attention to forces significantly different from those obtained by using DP capability level 1 calculation methods.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

SECTION 3 DP CAPABILITY LEVEL 1

3.1 Applicability

The method described in this section is valid for ship-shaped mono-hull vessels. All analyses of ship-shaped mono-hull vessels using this standard for documenting DP position keeping capability shall calculate and document the DP capability level 1 numbers.

Guidance note:

For other vessel shapes than ship-shaped mono-hull reference is made to DP capability level 2, DP capability level 2-site, DP capability level 3 and DP capability level 3-site. For monohulls where the ratios between beam and length over all, and/or beam and draft are higher than a typical ship-shaped monohull, or other hull characteristics are significantly different, like e.g. having more than one bulbous bow, then level 2 should be considered. A typical example may be self elevating ships or jack-up barges where level 1 may be applied when the legs are fully elevated. When legs are not fully elevated level 2 may be applied.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.2 Analysis method

3.2.1

The intention with DP capability level 1 is to provide non-conservative bench-marking figures. The prescriptive method described in this section shall be strictly followed without any deviations.

Guidance note:

In case project specific adjustments or inclusion of external forces are wanted, the DP capability may be documented according to DP capability level 2-site or DP capability level 3-site methods.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.2.2

Wind, current and wave forces, multiplied with a dynamic factor of 1.25, shall be statically balanced by the effective actuator forces in order to achieve the corresponding DP capability number. In addition the vessel shall be able to balance the wind, current and wave forces for all lower DP capability numbers, see [2.4.4].

3.2.3

External forces shall not be included in the DP capability level 1 calculation.

Guidance note:

For inclusion of external forces DP capability level 2-site and DP capability level 3-site calculations may be performed.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.3 Environment

3.3.1

The calculations shall assume coincident wind, wave and current directions.

3.3.2

The wind and current speeds shall be assumed to be vertically uniformly distributed.

3.3.3

The wave drift forces model shall be based on a Pierson Moskowitz wave spectrum with $\cos^2$ spreading. This means the relationship between *Tp* and *Tz* is *Tp* = 1.4049×*Tz*. The wave directional spreading function shall be defined as: $D(\theta) = \frac{\Gamma(1+n/2)}{\sqrt{\pi}\Gamma(1/2+n/2)}\cos^2\left(\theta - \theta_p\right)$, where Γ is the Gamma function and θ is the angle between the direction of elementary wave trains and the main wave direction θ_p of the short crested wave system, $\left|\theta - \theta_p\right| \le \frac{\pi}{2}$.

Guidance note:

For more information, see DNV-RP-C205.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.4 Environmental loads

3.4.1

Zero forward speed, summer load line draft and even keel shall be used.

3.4.2

Projected areas shall include everything on the vessel as if the area was calculated from a picture. The position of deck equipment and cranes used as basis for the calculations shall be indicated. Pods, propellers, rudders and similar devices shall also be included.

Guidance note:

General arrangement drawings are often a good basis. When representing an insignificant part of the total area, smaller shapes like wires and antennas may not need to be included.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.5 Wind

The forces from wind loads shall be calculated using the following formulas:

$$F_{X,wind} = \frac{1}{2}\rho_{air}V_{wind}^2 A_{F,wind} \cdot \left(-0.7 \cdot \cos(direction)\right)$$

$$F_{Y,wind} = \frac{1}{2}\rho_{air}V_{wind}^2 A_{L,wind} \cdot \left(0.9 \cdot \sin(direction)\right)$$

$$dir = \begin{cases} direction, \ 0 \le direction \le \pi, \\ 2\pi - direction, \pi \le direction \le 2\pi \end{cases}$$

$$M_{Z,wind} = F_{Y,wind} \cdot \left(x_{L,air} + 0.3 \cdot \left(1 - 2 \cdot \frac{dir}{\pi}\right) \cdot L_{pp}\right)$$

where:

$direction$	=	wind coming from direction
$A_{F,wind}$	=	frontal projected wind area as from a picture in front view
$A_{L,wind}$	=	longitudinal projected wind area as from a picture in side view
$X_{L,air}$	=	longitudinal position of the area center of $A_{\mathrm{L,wind}}$

ρ_{air}	=	air density
	=	1.226 kg/m^3.

Guidance note:

Deck equipment is assumed to be in parked position.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.6 Current

The forces from current loads shall be calculated using the following formulas:

$$F_{X,current} = \frac{1}{2}\rho_{water}V_{current}^2 B \cdot draft \cdot \left(-0.07 \cdot \cos(direction)\right)$$

$$F_{Y,current} = \frac{1}{2}\rho_{water}V_{current}^2\ A_{L,current} \cdot \left(0.6 \cdot \sin(direction)\right)$$

$$dir = \begin{cases} direction,\ 0 \le direction \le \pi, \\ 2\pi - direction, \pi \le direction \le 2\pi \end{cases}$$

$$M_{Z,current} = F_{Y,current} \cdot \left(x_{L,current} + \max\left(\min\left(0.4 \cdot \left(1 - 2 \cdot \frac{dir}{\pi}\right), 0.25\right), -0.2\right) \cdot L_{pp}\right)$$

where:

$A_{L,current}$	=	longitudinal projected submerged current area as from a picture in side view
$direction$	=	current speed coming from direction
B	=	maximum breadth at water line
$draft$	=	summer load line draft
$X_{L,current}$	=	longitudinal position of the area center of $A_{L,current}$
ρ_{water}	=	water density
	=	1026 kg/m^3.

Guidance note:

When the above formulas are used for calculating DP capability level X-site results, i.e. when the current speed differs from the environment specified in Table 2-1, it has to be noted that the formulas are applicable up to moderate current speeds (Froude number with respect to breadth less than 0.1, i.e. $V_{current} < 0.1 \cdot \sqrt{g \cdot B}$) where free surface effects are neglectable. Hence, when calculating DP capability level X-site results, these formulas should be used with care.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.7 Waves

Wave drift forces shall be calculated using the following formulas:

$$F_{X,wave} = \frac{1}{2}\rho_{water}gH_s^2B \cdot h\left(direction, bow_{angle}, C_{WLaft}\right) \cdot f\left(T'_{surge}\right)$$

$$h\left(direction, bow_{angle}, C_{WLaft}\right) = 0.09 \cdot h_1\left(direction, bow_{angle}, C_{WLaft}\right) \cdot h_2\left(direction\right)$$

$$h_{1A}\left(bow_{angle}\right) = 0.8 \cdot bow_{angle}^{.45}$$

$$h_{1B}\left(C_{WLaft}\right) = 0.7 \cdot C_{WLaft}^2, C_{WLaft} \in \left[0.85, 1.15\right]$$

$$dir(direction) = \begin{cases} direction, \ 0 \le direction \le \pi, \\ 2\pi - direction, \pi \le direction \le 2\pi \end{cases}$$

$$h_1\left(direction, bow_{angle}, C_{WLaft}\right) = h_{1A}\left(bow_{angle}\right) + \frac{dir(direction)}{\pi}\left(h_{1B}\left(C_{WLaft}\right) - h_{1A}\left(bow_{angle}\right)\right)$$

$$h_2\left(direction\right) = 0.05 + 0.95 \cdot \arctan\left(1.45 \cdot \left(dir\left(direction\right) - 1.75\right)\right)$$

$$f(T') = \begin{cases} 1, if \ T' < 1 \\ T'^{-3} \cdot e^{1 - T'^{-3}}, if \ T' \ge 1 \end{cases}$$

$$F_{Y,wave} = \frac{1}{2}\rho_{water}\, g H_s^2\, L_{OS} \cdot \left(0.09 \cdot \sin(direction)\right) \cdot f\left(T'_{sway}\right)$$

$$M_{Z,wave} = F_{Y,wave} \cdot \left(x_{Los} + \left(0.05 - 0.14 \cdot \frac{dir(direction)}{\pi}\right) \cdot L_{OS}\right)$$

$$T'_{surge} = \frac{T_z}{0.9 \cdot L_{pp}^{0.33}}$$

$$T'_{sway} = \frac{T_z}{0.75 \cdot B^{0.5}}$$

where:

H_S	=	significant wave height
L_{OS}	=	longitudinal distance between the fore most and aft most point under water
L_{pp}	=	length between perpendiculars
X_{Los}	=	longitudinal position of $L_{os}/2$, see Figure 3-1
bow_{angle}	=	angle between the vessel x-axis and a line drawn from the foremost point in the water line to the point at y = $B/4$ (ahead of $L_{pp}/2$) on the water line, so the bow_{angle} = arctan(B/4/(xmax-xb4)), xmax is the longitudinal position of the foremost point in the water line, xb4 is the longitudinal position of the point in the water line at transverse position equal to $B/4$, see Figure 3-2
C_{WLaft}	=	water plane area coefficient of the water plane area behind midship. This value shall be limited to the range defined above, i.e. 0.85 shall be used if the calculated values is below 0.85, and 1.15 shall be used if the calculated values is above 1.15
	=	$A_{WLaft}/(L_{pp}/2*B)$
A_{WLaft}	=	water plane area for x < 0
$direction$	=	waves coming from direction.

Guidance note:

When the above formulas are used for calculating DP capability level X-site results, i.e. when the wave spectrum differ from Pierson Moskowitz or the wave spreading from $\cos^2$ (see DNV-RP-C205 [3.5.8.4]), these formulas are not applicable.

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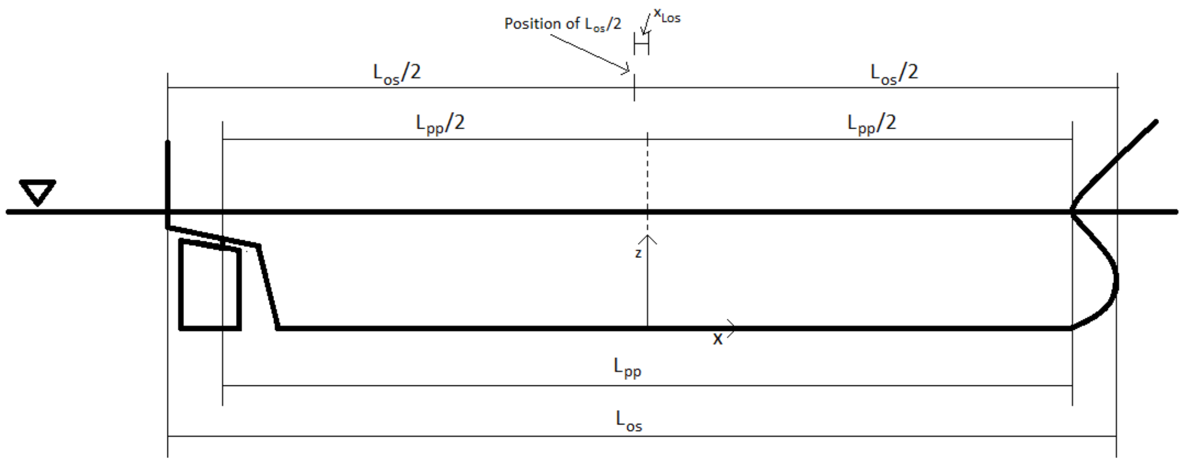

Figure 3-1 Vessel geometrical parameters for wave drift. x_{Los} has a negative value in this case

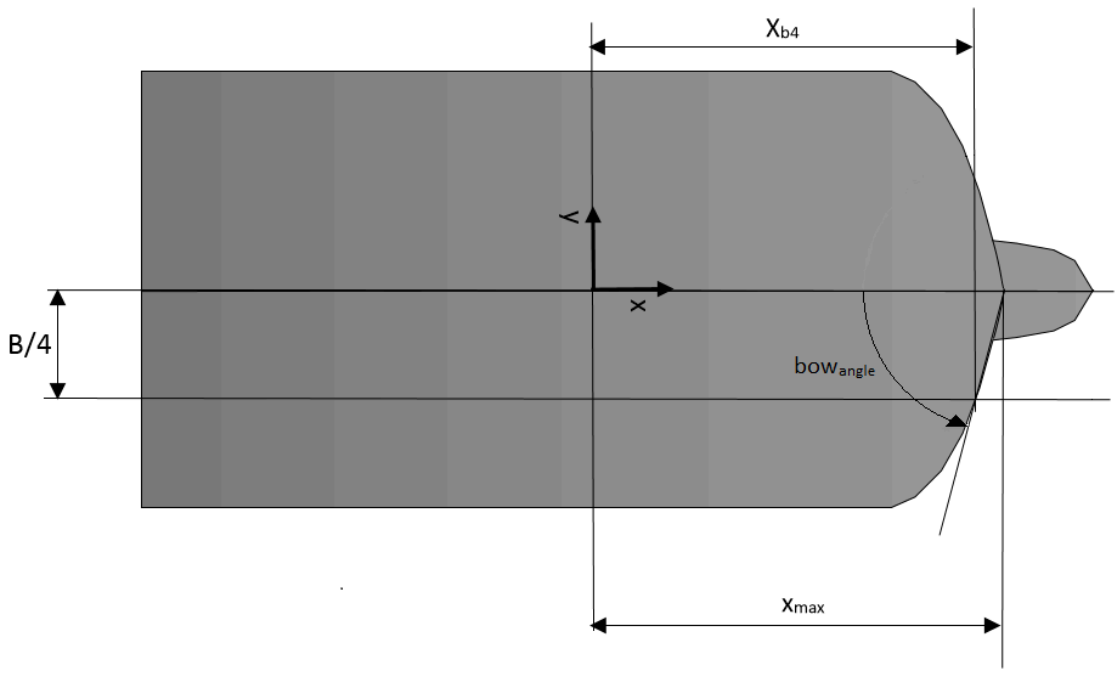

Figure 3-2 *Bow*$_{\mathbf{angle}}$ definition

3.8 Actuators

3.8.1

For actuator types which are not covered by this section, e.g. water jets, relevant data supplied by the manufacturer of the unit may be used. Such data shall be justified and made available.

3.8.2

The actuator/thruster angle is defined as 0 degree when the actuator longitudinal axis is parallel to the vessel *x* axis and the actuator/thruster is pushing forward. The actuator/thruster angle is increasing anti clockwise. This is illustrated in Figure 3-3.

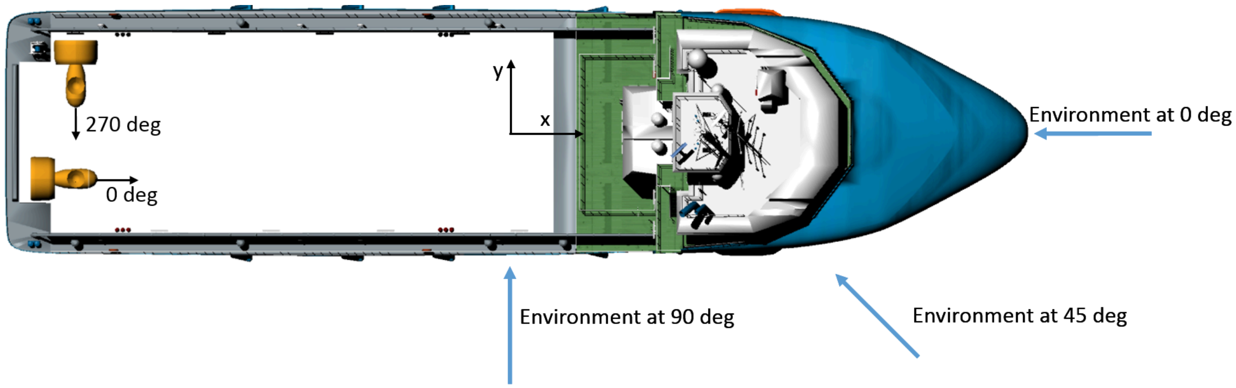

Figure 3-3 Actuator/thruster angle definition. The arrow in the thruster indicates the nominal force direction.

3.8.3

The position of the actuator unit is defined as:

— Tunnel thrusters: the volume centre of the tunnel.
— Azimuths: the intersection of the propeller shaft and the azimuthing axis.
— Shaft propellers without rudder: the centre of the hub.
— Shaft propellers with rudder: the intersection of the rudder stock and the propeller axis.
— Cycloidals: the centre of the rotation mechanism half way down the blades.

3.9 Effective thrust

3.9.1

The available thrust force from an actuator shall be calculated as:

$$T_{Effective} = T_{Nominal}\,\beta_T$$

Where $T_{\text{Effective}}$ is the effective thrust, T_{Nominal} is the nominal thrust and β_T is the thrust loss factor.

3.9.2

The nominal thrust shall be calculated from the following formula:

$$T_{Nominal} = \eta_1 \eta_2 (D \times P)^{2/3}$$

where:

nominal thrust $(T_{Nominal}\,[N])$	=	thrust with no wind, waves or current present
D	=	propeller diameter in meter
P	=	the power applied to the propeller in kW.

Guidance note 1:

For permanent magnet tunnel thrusters *D* is defined as the diameter of the circle created by the blade tips.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

For contra-rotating propellers and pods with one propeller in each end of the pod house, *D* is defined as the diameter of the largest propeller.

Guidance note 2:

Propellers placed in immediate vicinity of each other are considered as a contra-rotating unit. Pods with one propeller on each side of the pod house are not considered to be contra-rotating propellers.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

For cycloidal actuators, *D* is defined as the geometrical average of blade length and diameter of blade pivot points: $= \sqrt{blade\ length \cdot diameter\ of blade\ pivot\ points}$

The power applied to the propeller, *P*, is defined as:

$$P = P_B \eta_M$$

where:

η_M	=	the mechanical efficiency
P_B	=	the MCR brake power available in DP mode/bollard pull, i.e. taking power and torque limitations etc. into account.

The break power of propulsion motors shall be considered. Power and torque limitations relevant in the considered DP mode shall be documented.

Guidance note 3:

For dedicated DP actuators, CPP propellers and cycloidals the torque limitation in DP mode need not to be documented. For other actuators where torque limitations are not documented it may be accepted to apply 50% of MCR as P_B.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

The efficiency factor η_1 is given in Table 3-1 below:

Table 3-1 η_1

Type of actuator	η_1
Azimuths, pods and shaft line propellers	800
Cycloidal actuators	900
Tunnel thrusters	900

Type of actuator	η_1
Contra-rotating azimuths, pods and shaft line propellers	950
Ducted azimuths, pods and shaft line propellers	1200

The efficiency factor η_2 is given in Table 3-2 and Table 3-3 below:

Table 3-2 η_2 for tunnel thrusters

Inlet shape	η_2
For broken inlets with $\alpha \in$ [20,50]deg and b > 0.1D	1.0
For rounded inlet with r > 0.05D	1.07
For all other inlet shapes	0.93

where:

— α is angle between tunnel wall and cone.
— b is the smallest breadth of the cone.
— r is the smallest radius of the rounding.
— D is propeller diameter.

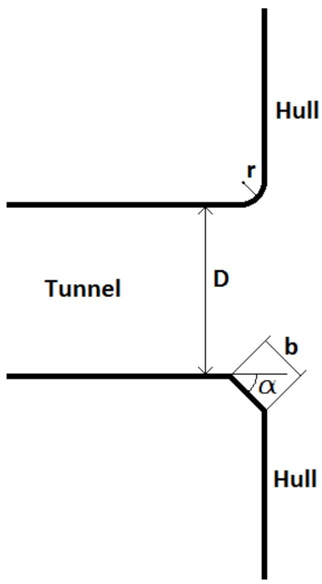

Figure 3-4 Inlet and outlet of tunnels

Table 3-3 The efficiency factor η_2 for actuators other than tunnel thrusters

Thrust direction and type of actuator	η_2
Forward thrust	1.0

Thrust direction and type of actuator	η_2
Reversed thrust from FPP propellers without duct	0.9
Reversed thrust from FPP propellers with duct	0.7
Reversed thrust from CPP propellers without duct	0.65
Reversed thrust from CPP propellers with duct	0.5

Guidance note:

For FPP, reversed thrust shall be understood as the thrust when the propeller is rotating opposite of its design-direction.

Contra-rotating actuators typically have FPP propellers and no duct.

Cycloidal actuators are typically not reversed and hence η_2 is set to 1.0.

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The mechanical efficiency η_M is given in Table 3-4 below:

Table 3-4 Mechanical efficiency

Type of actuator	η_M
Cycloidal actuators	0.91
Permanent magnet cycloidal actuators	0.97
Tunnel and azimuth thrusters	0.93
Rim-driven permanent magnet actuators	0.995
Shaft line propellers	0.97
Pods	0.98

3.9.3

To account for inline losses, cross flow losses, fouling, anodes, and ice, a constant thrust loss of 10% is applied. This gives $\beta_{misc} = 0.9$.

Guidance note:

Actuator interaction effects are handled in [3.11] thrust allocation.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.9.4

Ventilation losses shall be calculated by the following formulas:

$$\beta_{vent} = \Phi\left(k_{V1}\frac{2 \cdot \xi}{D} - k_{V2}\sigma\right)$$

$$\sigma = 0.25 \cdot \left(A \cdot H_S \cdot \min\left(T_0, 1\right) + \max(\text{PropellerLoadFactor} - 1, 0)\right)$$

$$A = k_{V4} \cdot B \cdot C$$

$$B = \begin{cases} 1 + k_{V5} \cdot \frac{abs(direction)}{\pi}, direction \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right] \\ (1 + k_{V5}) - k_{V5} \cdot \frac{abs(direction)}{\pi}, direction \in \left[-\pi, -\frac{\pi}{2}\right] \cap \left[\frac{\pi}{2}, \pi\right] \end{cases}$$

$$C = \begin{cases} 1, x \geq 0 \\ 1 + 0.4\frac{x}{L_{PP}}, x \leq 0 \end{cases}$$

$$T_0 = 0.64\frac{\sqrt{L_{pp}}}{T_z}$$

$$\text{PropellerLoadFactor} = \frac{\sqrt{\text{PropellerLoad}}}{k_{V3}}$$

$$\text{PropellerLoad} = \frac{abs(T_{Nominal})}{D^3}$$

where:

β_{vent}	=	thrust loss factor
Φ	=	cumulative normal distribution function with mean = 0 and standard deviation = 1
ξ	=	$draft - actuator\ z\ position$; where ξ is the actuator submergence, see [3.8.3]. Hence, ξ shall be positive if it is submerged (i.e. ξ=0 corresponds to the actuator center being at the waterline)
D	=	propeller diameter
σ	=	standard deviation of the relative vertical motion between the actuator and the free surface
H_s	=	significant wave height
x	=	thruster's x position
T_z	=	zero-up-crossing period of wave spectrum
$direction$	=	wave coming from direction
$T_{Nominal}[N]$	=	Actuator nominal thrust (thrust before losses)
k_{V1}	=	2
k_{V2}	=	1.5
k_{V3}	=	15.2
k_{V4}	=	0.85
k_{V5}	=	0.38.

3.9.5

The total thrust loss factor is given as:

$$\beta_T = \beta_{misc} \cdot \beta_{vent}$$

3.10 Rudders

3.10.1

For a rudder behind a propeller giving positive thrust the effect of rudder shall be accounted for with the following equations.

The forces produced by the sum of the propeller and the rudder are given by:

$$F_{Surge} = T_{Effective}\left(1 - C_x \alpha^2\right)$$

$$F_{Sway} = T_{Effective} C_y \alpha$$

Where α is the rudder angle in degrees. For rudder angle above 30 degrees values for 30 degrees shall be used.

The lift and drag coefficients C_X and C_Y are given as:

$$C_x = 0.02 C_y$$

$$C_Y = 0.0126 k_1 k_2 \frac{A_r}{D^2}$$

Where A_r is the area of the movable part of the rudder directly behind the propeller. When computing this area the chord length at any position is limited to maximum 1.0D.

Factor k_1 are given in Table 3-5, and factor k_2 are given in Table 3-6 (see Figure 3-5 for examples of rudder profiles).

Table 3-5 Rudder profile type – coefficient (k_1)

Profile type	*Ahead*
NACA – Göttingen	1.1
Hollow profile 1)	1.35
Flat-sided	1.1
Profile with «fish tail»	1.4
Rudder with flap	1.65
Nozzle rudder	1.9
Mixed profiles (e.g. HSVA)	1.21
1) Profile where the width somewhere along the length is 75% or less of the width of a flat side profile with same nose radius and a straight line tangent to aft end.	

Table 3-6 Rudder/nozzle arrangement– coefficient (k_2)

Rudder/nozzle arrangement	k_2
All other arrangements	1.0
For rudders behind a fixed propeller nozzle	1.15

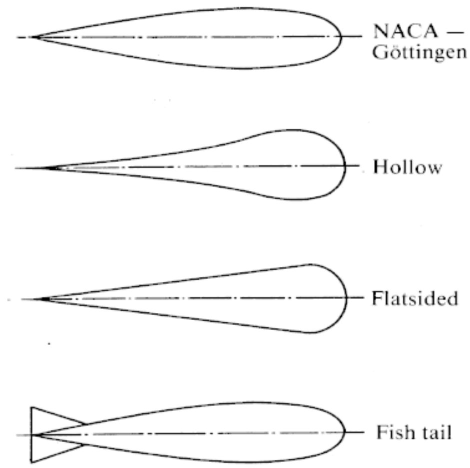

Figure 3-5 Example of rudder profiles

3.10.2

For a rudder behind a propeller giving negative thrust the effect of the rudder shall be neglected.

3.11 DP control system and thrust allocation

3.11.1

The DP control system shall calculate the necessary actuator forces, and their directions, to find the balance between the environmental forces and actuator forces.

Guidance note:

The thrust allocation utilized in the analysis calculation may not be the same as the one that will be implemented in the DP control system on the actual vessel. This may result in different thrust allocation solutions between the analysis and the actual DP control system.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.11.2

Forbidden zones and other possible limitations in the thrust allocation shall be specified in the report in the form of a figure and in a table, and the effects of these forbidden zones shall be included in the calculations.

Guidance note:

Forbidden zones/reduced thrust zones may be caused by e.g. an azimuth thrusting in to the rudders and/or working actuators.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.11.3

A thruster flushing a working thruster shall be handled as follows:

A thruster is flushing another working thruster if the angle between the thrust direction (vector through propeller shaft for non-cycloidal actuators pointing in the same direction as the thrust force) and the vector from the flushed thruster to the flushing thruster is less than $\arctan\left(0.1 + \frac{1.0D}{s}\right)$ [deg] (D is the diameter of the flushing thruster and s is the horizontal distance between the thrusters). All angles and lengths are given in the horizontal plane.

A thruster is not allowed to flush a working thruster closer than 15D, unless the flushed thruster is a tunnel thruster.

3.11.4

A thruster flushing a dead thruster shall be handled as follows:

A thruster is flushing a dead thruster if the angle between the thrust direction and the vector from the flushed thruster to the flushing thruster is less than $\arctan\left(\frac{0.6D}{s}\right)$ [deg] for open flushing propellers and $\arctan\left(\frac{0.35D}{s}\right)$ [deg] for ducted flushing propellers (D of the flushing thruster). All angles are given in the horizontal plane.

A thruster is allowed to flush a dead tunnel thruster.

A thruster flushing a dead thruster not being a tunnel thruster closer than 8D for open propellers and 4D for ducted propellers shall have an additional thrust loss factor when pointing directly towards the other thruster equal to:

$$1 - \frac{1}{0.02\left(\frac{s}{D}\right)^2 + 0.25\frac{s}{D} + 1.2}$$

resulting in:

$$\beta_{T,flushing\ dead} = \left(1 - \frac{1}{0.02\left(\frac{s}{D}\right)^2 + 0.25\frac{s}{D} + 1.2}\right)$$

This effect shall be linearly interpolated in Cartesian coordinates between pointing directly towards the other thruster and the sector limits as seen in Figure 3-6.

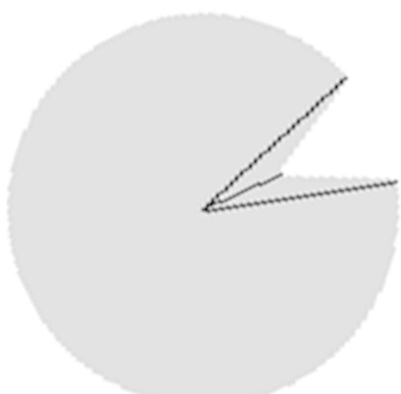

Figure 3-6 Thrust loss when flushing a dead thruster (other than a tunnel thruster)

3.11.5

A thruster flushing the hull shall be handled as follows:

For mono-hull it is reasonable to assume that the skeg or gondola is the only part of the hull which any thruster may flush. For hulls with one or more skeg(s) or gondola(s) in the aft, the following applies to all thruster placed above the base line, except tunnel thrusters.

An additional thrust loss factor due to the skeg shall be applied when the shortest distance between the thruster and a vertical plane going forward along the x-axis from the aft most point on the skeg or gondola is less than 15*D* for open propellers and 8*D* for ducted propellers, and the propeller is not directly behind the skeg.

For thrusters on port side, the additional thrust loss factor due to skeg(s) is defined by the following equations:

$$\alpha_{flush} = \frac{\pi}{2} - \arctan\left(\frac{x_{skeg} - x_{thr}}{y_{skeg} - y_{thr}}\right)$$

$$\alpha_{\max loss} = \min\left[\max\left[\alpha_{flush} + \alpha_{jet}, \frac{\pi}{2}\right], \pi\right]$$

Table 3-7 Port thrusters skeg loss factor

Thrust direction	*Thrust loss factor due to skeg*
$0 \ to \ \max\left[\alpha_{flush} - \alpha_{jet}, 0\right]$	1
$\alpha_{\max loss}$	$\left[2\frac{\alpha_{\max loss}}{\pi} - 1\right]$
$\min\left[\alpha_{\max loss} + 4\alpha_{jet}, \pi\right] \ to \ 2\pi$	1

For thrusters on starboard side, the additional thrust loss factor due to skeg(s) is defined by the following equations:

$$\alpha_{flush} = \frac{3\pi}{2} - \arctan\left(\frac{x_{skeg} - x_{thr}}{y_{skeg} - y_{thr}}\right)$$

$$\alpha_{\max loss} = \max\left[\min\left[\alpha_{flush} - \alpha_{jet}, \frac{3\pi}{2}\right], \pi\right]$$

Table 3-8 Starboard thrusters skeg loss factor

Thrust direction	*Thrust loss factor due to skeg*
$\pi \ to \ \max\left[\alpha_{\max loss} - 4\alpha_{jet}, \pi\right]$	1
$\alpha_{\max loss}$	$\left[3 - 2\frac{\alpha_{\max loss}}{\pi}\right]$

Thrust direction	Thrust loss factor due to skeg
$\min\left[\alpha_{flush}+\alpha_{jet}, 2\pi\right]\ to\ 2\pi$	1

where:

$$\alpha_{jet}(s) = \arctan\left(\frac{0,6D}{s}\right)$$

$$s = \begin{cases} \sqrt{\left(x_{skeg}-x_{thr}\right)^2+\left(y_{skeg}-y_{thr}\right)^2}, x_{skeg} > x_{thr} \\ \left|y_{skeg}-y_{thr}\right|, x_{skeg} \leq x_{thr} \end{cases}$$

D = the diameter of the flushing thruster

α_{flush} = the actuator angle at which the undisturbed actuator wake is directed towards the aft most point on the skeg

s = the shortest horizontal distance between the thruster and the skeg

x_{skeg} = the x-position of the aft most position of the skeg or gondola

y_{skeg} = the y-position of the aft most position of the skeg or gondola.

Guidance note:

The aftmost point on a skeg is defined independently of any water line or vertical position of the thruster considered. I.e. the x, y and z coordinate of the aftmost point on the skeg is a property of the vessel.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

For thrust directions between listed values, linear interpolation in polar coordinates shall be applied.

An example of the loss factor for a port aft azimuth thruster is given in Figure 3-7.

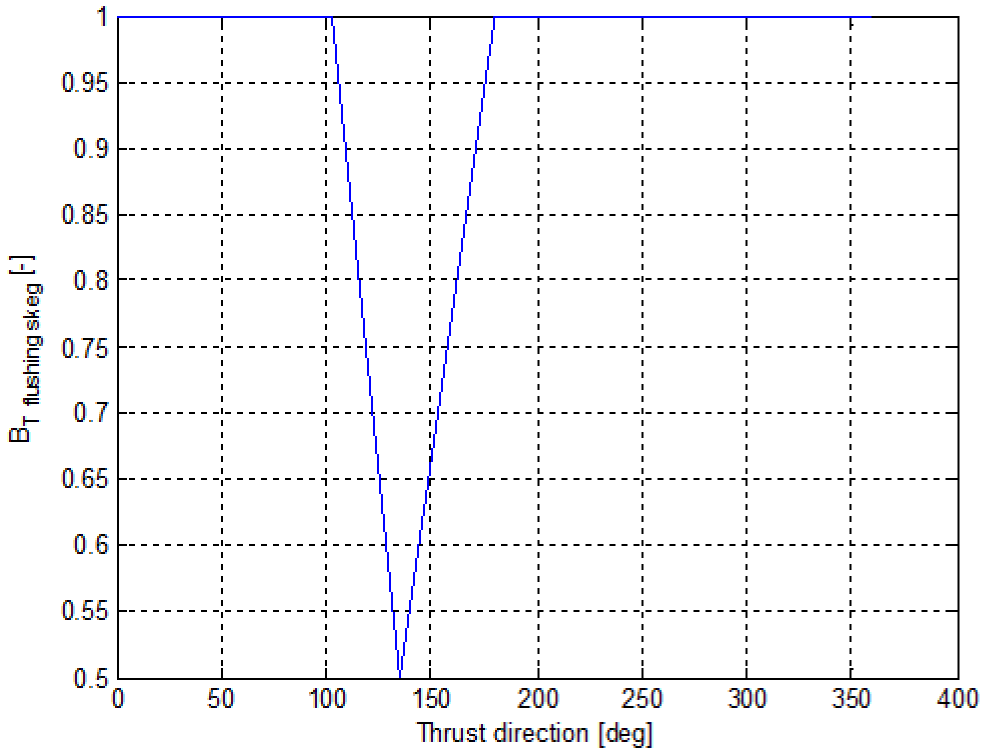

Figure 3-7 Example of thrust loss factor due the skeg for a port aft azimuth thruster

The result is:

$$\beta_{T,flushing\,skeg} = Thrust\ \ loss\ \ factor\ \ due\ to\ skeg$$

3.11.6

The total thrust loss factor is given as:

$$\beta_T = \beta_{misc} \times \beta_{vent} \times \beta_{T,flushing\ dead} \times \beta_{T,flushing\ skeg}$$

Guidance note:

If $\beta_{T,flushing\ dead}$ or $\beta_{T,flushing\ skeg}$ are not applicable, and can be taken as 1.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.12 Power generation

3.12.1

The DP system operating mode(s) shall be specified. As a minimum this applies to:

— switchboard set-up, open/closed bus-ties, number of running and stand-by gen-sets and other prime movers
— set-up of dual supplies to thrusters, if arranged
— set-up of other major consumers, when relevant.

3.12.2

When batteries are included in the DP capability assessment, the battery power to be used in the calculations shall be based upon 80% to 20% state of charge (at the beginning of life, BOL), and the battery system maximum discharge rate in kW at 20% state of charge (at BOL). The energy source shall be able to supply the power at the considered rate for minimum 30 minutes. In case there are battery system control and/or safety functions reducing the above stated power and/or energy levels this shall be accounted for. In case such reductions are accounted for this shall be specified in the calculations.

Guidance note 1:

If a battery is normally used from 80% to 20% state of charge, and the nominal maximum energy is 1000 kWh (at BOL), then the maximum available power for one hour will be 600 kW, or 1200 kW for 30 minutes provided the maximum rate of discharge allows that. In case the maximum rate of discharge (in kW at 20% state of charge, at BOL) is lower than the one needed to reach the above power levels (600 kW for one hour, or 1200 kW for 30 minutes),, then this maximum available power level is the correct power level to be used in the calculations.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Guidance note 2:

When relevant, reductions in the available maximum battery power and/or energy due to the way the battery is used during DP operations, temperature, or other effects should be accounted for in the calculations.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

3.12.3

Calculations shall be in accordance with the vessel power consumption balance. This shall be evaluated and documented in the report. For each redundancy group, 10% of electrical generated power shall be reserved for hotel and consumers not part of the thruster system.

3.12.4

Electrical losses from generated power to actuators (e.g. losses from switchboards, transformers, variable frequency drives, electrical motors, breakers) are included in the 10% reserved power and shall not be added separately.

3.12.5

For each calculated condition, the thrust utilization, thrust loss factor and power utilization at the switchboard level shall be documented in a tabulated format. The thrust utilization is defined in [2.4.6].

SECTION 4 DP CAPABILITY LEVEL 2

4.1 Objective

The purpose of DP capability level 2 is to allow for improved evaluation of DP capability compared to DP capability level 1 by use of enhanced methods to compute environmental loads and actuator forces. Deviations from DP capability level 1 method and any project specific data applied shall be justified and documented.

DP capability level 2 may e.g. be used for:

— comparing enhanced computation methods with DP capability level 1
— calculating capability for and comparing vessels with shapes not applicable to DP capability level 1.

4.2 Application

4.2.1

The method described in this section is valid for all vessel shapes.

4.2.2

External forces shall not be included in the DP capability level 2 calculation.

Guidance note:

For inclusion of external forces DP capability level 2-site and DP capability level 3-site calculations may be performed.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.3 Analysis method for DP capability level 2

4.3.1

Wind, current and wave forces, multiplied with a dynamic factor, shall be statically balanced by the effective actuator forces in order to achieve the corresponding DP capability number. In addition the vessel shall be able to balance the wind, current and wave forces for all lower DP capability numbers, see [2.4.4].

4.3.2

The dynamic factor shall account for time varying dynamics and should be considered for the specific vessel. Different dynamic factors for each environmental load may be applied.

Guidance note:

Typical factors which are important when considering dynamic factors are: Vessel size, vessel shape, thruster response time and thruster layout. Recent research on semi-submersible units indicates that in severe sea states with large current speeds the second-order wave-drift forces may be larger than typical values obtained by use of classical potential theory. For semi-submersibles it should be considered if this could be accounted for by adapting the wave dynamic factor.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.3.3

As an alternative to or in combination with the dynamic factor on the environmental loads, dynamic effects may be accounted for by introducing additional reduction, as compared to DP capability level 1, on the nominal thrust and/or available power.

Guidance note:

In case additional power reduction is introduced, e.g. 10% in addition to the power reserve required by DP capability level 1, then the total power reduction used in the calculation will be a 20% reduction of the total available power.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.4 Environment

The environment shall be the same as in DP capability level 1.

4.5 Environmental loads

Zero forward speed, summer load line draft and even keel shall be used. For vessels without a defined summer load line draft, the draft shall be the deepest approved operating draft.

4.6 Wind

4.6.1

For ship-shaped mono-hulls, wind loads for DP capability level 2 calculations can be based on the DP capability level 1 method.

4.6.2

For hull shapes other than mono-hulls, wind force calculations shall be based on recognized methods. For semi-submersibles, see DNV-RP-C205.

4.6.3

Wind forces may alternatively be computed by other recognized methods. In this case the method shall represent a significant improvement in the accuracy of the predicted load compared to DP capability level 1. Use of such methods shall be justified and documented.

When applying such methods, validation reports shall be made available upon request. The validation report shall demonstrate the applicability and accuracy of the applied method in the actual application.

Guidance note:

Suggested methods with significant improvement in accuracy are model tests and RANSE simulations.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.6.4

If the wind load is not computed according to DP capability level 1, the results shall be compared to the level 1 method as function of heading for the DP capability level 1 B and D numbers, see App.A.

4.7 Current

4.7.1

For ship-shaped mono-hulls, current loads for DP capability level 2 calculations can be based on the DP capability level 1 coefficients.

4.7.2

For hull shapes other than mono-hulls, current force calculations shall be based on recognized methods.

4.7.3

Current forces may be computed by other recognized methods. In this case the method shall represent a significant improvement in the accuracy of the predicted load compared to DP capability level 1. Use of such methods shall be justified and documented.

When applying such methods validation reports shall be available upon request. The validation report shall demonstrate the applicability and accuracy of the applied method in the actual application.

Guidance note:

Suggested methods with significant improvement in accuracy are model tests and RANSE simulations.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.7.4

If the current load is not computed according to DP capability level 1, the results shall be compared to the level 1 method as function of heading for the DP capability level 1 B and D numbers, see App.A.

4.8 Waves

4.8.1

For ship-shaped mono-hulls, wave loads for DP capability level 2 calculations can be based on the DP capability level 1 method.

4.8.2

For hull shapes other than mono-hulls, wave force calculations shall be based on recognized methods.

4.8.3

Wave forces may be computed by other recognized methods. In this case the method shall represent a significant improvement in the accuracy of the predicted load compared to DP capability level 1. Use of such methods shall be justified and documented.

Guidance note:

Suggested methods with significant improvement in accuracy are model tests and CFD (including potential theory) simulations.

When applying such methods, validation reports shall be available upon request. The validation report must demonstrate the applicability and accuracy of the applied method in the current application.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.8.4

If the wave load is not computed according to DP capability level 1, the results shall be compared to the level 1 method as function of heading for the DP capability level 1 B and D numbers, see App.A.

4.9 Actuators

4.9.1

Actuator forces for DP capability level 2 calculations can be based on the DP capability level 1 method.

4.9.2

Propulsion forces may be computed by other recognized methods. In this case the method shall represent a significant improvement in the accuracy of the predicted force compared to DP capability level 1. Use of such methods shall be justified and documented.

When applying such methods validation reports shall be available upon request. The validation report shall demonstrate the applicability and accuracy of the applied method in the current application.

Guidance note:

Suggested methods with significant improvement in accuracy are model tests and CFD (including potential theory) simulations. In addition, more refined empirical methods may be applied for thrust losses.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.9.3

The actuator forces shall be compared to the level 1 method when they are not computed according to DP capability level 1.

4.9.4

Comparison of thrust and rudder forces, computed from DP capability level 1 and DP capability level 2 shall be documented (when applicable). See App.A for details on requirements. Significant discrepancies between the results from DP capability level 2 and DP capability level 1 shall be justified.

4.10 DP control system and thrust allocation

Forbidden zones and other possible limitations in thrust allocation shall be documented in the report in the form of a figure and in table(s). The effects of these forbidden zones shall be included in the calculations.

Guidance note:

Forbidden zones/reduced thrust zones may be caused by e.g. an azimuth thrusting in to the skeg/rudder/working actuator. DP capability level 2 forbidden zones can be based on the DP capability level 1 method. Additional effects which may limit the thrust, compared to the DP capability level 1 method, have also to be considered. An example of such effects may e.g. be twin hull interaction.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.11 Power generation

4.11.1

DP capability level 2 calculations shall be based on the DP capability level 1 method. In case project specific data are applied, these shall be justified and documented.

Guidance note:

The percentage of electrical generated power to be reserved for hotel and consumers not part of the thruster system may be fine tuned based on project specific data. This may also be done for electrical losses from generated power to actuators.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.11.2

In case limited energy sources like e.g. batteries are included in the DP capability assessment, the battery power to be used in the calculations should be based upon the normal operating range of the battery state of charge and maximum discharge rate in that range. The energy source shall generally be able to supply the power at the considered rate for the specified time needed to safely terminate the operation. In case there are battery system control and/or safety functions reducing the above stated power and/or energy levels this shall be accounted for. In case such reductions are accounted for this shall be specified in the calculations.

Guidance note:

When relevant, reductions in the available maximum battery power and/or energy due to the way the battery is used during DP operations, temperature, or other effects should be accounted for in the calculations.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

SECTION 5 DP CAPABILITY LEVEL 2-SITE

5.1 Objective

The purpose of DP capability level 2-site is to allow for improved evaluation of DP capability compared to DP capability level 2 by use of site specific environmental conditions and also with external loads included, when relevant.

DP capability level 2-site may e.g. be used for:

— assessing the DP capability in site specific environmental conditions, specific vessel load conditions, and with external loads included.

Guidance note:

The vessel load condition may be selected based on the vessel operation, thus the draft is not required to be the summer load draught as for level 1 and level 2.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.2 Application

5.2.1

The method described in this section is valid for all vessel shapes.

5.2.2

External forces may be included in the DP capability level 2-site calculation. The magnitude of the force, its direction and the application point on the vessel shall be specified and documented.

5.3 Analysis method for DP capability level 2-site

5.3.1

Wind, current, wave, multiplied with a dynamic factor, and external forces shall be statically balanced by the effective actuator forces. Dynamic factors may also be applied to external forces when relevant.

5.3.2

The dynamic factor shall account for time varying dynamics and should be considered for the specific vessel. Different dynamic factors for each environmental load may be applied.

Guidance note:

Typical factors which are important when considering dynamic factors are: Vessel size, vessel shape, thruster response time and thruster layout. Typically, a semi-submersible is expected to have a smaller dynamic factor compared to a mono-hull vessel.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.3.3

As an alternative to or in combination with the dynamic factor on the environmental loads, dynamic effects may be accounted for by introducing a reduction on the nominal thrust and/or available power.

5.3.4

The site specific environmental conditions and external forces shall be specified in the DP capability level 2-site report.

5.4 Environment

In DP capability level 2-site calculations, the user is free to choose the environment. For a thorough description of the environmental variables see DNV-RP-C205. In addition to level 1 and level 2 environmental variables, the most relevant environmental variables for a DP analysis are:

— wind, waves and current may not be collinear
— other combinations of wind speed, current speed, wave height and wave period
— different wave spectrum and wave spreading
— swell.

Guidance note:

For wind, typically 1-min average wind speed at 10 m above sea level should be used.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.5 Environmental loads

Zero forward speed shall be used. The user is free to define the loading condition and operating mode of the vessel, including but not limited to draft, trim, projected areas, forbidden zones and external loads.

5.6 Wind

Wind loads for DP capability level 2-site shall be calculated based on the DP capability level 2 method, as given in section [4.6].

5.7 Current

Current loads for DP capability level 2-site shall be calculated based on the DP capability level 2 method. If DP capability level 2-site uses DP capability level 1 method, then this method is applicable only for moderate current speeds where free surface effects are neglectable.

Guidance note:

When calculating DP capability level 2 as required for comparison with DP capability level 1, the DP capability level 2 calculation must use the same method as DP capability level 2-site.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.8 Waves

Wave loads for DP capability level 2-site calculations shall be based on the DP capability level 2 method. If DP capability level 2-site uses DP capability level 1 method, then this method is applicable only for the Pierson Moskowitz wave spectra with $\cos^2$ spreading.

5.9 Actuators

Actuator forces for DP capability level 2-site calculations shall be based on the DP capability level 2 method.

Guidance note 1:

If DP capability level 2-site uses DP capability level 1 method for the calculation of thrust losses due to ventilation, then the formula for σ in [3.9.4] may be applied to Pierson Moskowitz and JONSWAP wave spectra with spreading factor from $\cos^2$ to $\cos^8$, see DNV-RP-C205 [3.5.8.4].

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.10 External forces

DP capability level 2-site calculations may include external forces from e.g. pipe-laying, drilling risers, mooring lines. Such external forces shall be included as mean loads and shall be documented in the report.

5.11 DP control system and thrust allocation

5.11.1

The DP control system shall calculate the necessary actuator forces and their directions to find the balance between the environmental forces and actuator forces.

Guidance note:

The thrust allocation utilized in the analysis calculation may not be the same as the one that will be implemented in the DP control system on the actual vessel. This may result in different thrust allocation solutions between the analysis and the actual DP control system.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

5.11.2

Thrust allocation in DP capability level 2-site calculations shall be based on the DP capability level 2 method.

5.12 Power generation

5.12.1

DP capability level 2-site calculations shall be based on the DP capability level 2 method.

SECTION 6 DP CAPABILITY LEVEL 3

6.1 Objective

6.1.1

The purpose of DP capability level 3 is to get more insight on the vessel's DP capability performance by use of time-domain simulations. Simulations are performed with a vessel model controlled by a DP control system which may or may not be the same control system supplied by the DP control system maker. By performing time-domain simulations and including the relevant dynamics, DP capability level 3 may provide more information about the station keeping performance than the other DP capability levels, such as statistics of the vessel position and heading, thruster and power utilization, and of other relevant vessel states.

6.1.2

The purpose of DP capability level 3 is to assess the effect of dynamics on the DP performance. Relevant dynamics are:

— vessel dynamics
— environmental load dynamics
— actuators dynamics
— DP control system dynamics.

6.1.3

DP capability level 3 is designed to evaluate the DP performance of vessels in a specified environment (same as in DP capability level 1 and DP capability level 2) and with specified positioning limits. The results from DP capability level 3 may be used to compare the DP performance of different vessels.

6.2 Application

6.2.1

The method described in this section is valid for all vessel shapes.

6.2.2

External forces shall not be included in the DP capability level 3 calculation.

6.3 Analysis method

6.3.1

The DP capability level 3 shall be determined based on environment, loading condition and operating mode as defined in DP capability level 1. For vessels without a defined summer load line draft, the draft shall be the deepest approved operating draft.

6.3.2

Zero forward speed shall be used for the analysis.

6.3.3

DP capability level 3 shall be computed performing simulations in the time-domain with a mathematical model of the vessel in closed-loop with a DP control system. The DP control system may be a model or the same control system supplied by the DP control system maker. The time-domain simulation implies that the vessel is free to move and the analysis is based on the evaluation of a simulated vessel footprint.

6.3.4

The vessel shall be considered in station keeping if it can maintain position and heading within the limits for 3 simulated hours for a given environmental condition.

Guidance note:

The results of the station keeping capability may vary a lot depending on the simulated time-window for each wave realization. Referring to DNV-RP-C205, the period in which the sea is stationary can range from 30 minutes to 10 hours. A typical simulated time-window when looking at extreme position excursions is 3 hours.

In order to provide a framework for comparing the performance of different vessels, the simulated time-window for level 3 is fixed to 3 hours. However, statistics of position and heading (and other vessel states) for shorter time-windows inside the 3-hours simulation may also be provided. This may be, for example, the worst and the best X-minute time-window capability.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.3.5

Simulation sampling time shall be fast enough to capture vessel dynamics including vessel motion, actuator systems, sensors, power generation, and DP control system dynamics, as well as relevant effects of environmental load dynamics.

6.3.6

The analysis shall be performed such that the results are statistically valid. As a minimum, 3 different wave realizations shall be simulated for each environmental direction. For each environmental direction, the final result shall be selected as the worst case result from the simulations, which means the lowest DP capability number (or lowest wind speed) from the used wave realizations.

Guidance note:

To obtain statistically valid results, the results may be obtained by running several simulations employing different 3-hours wave realizations.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.3.7

Average values, standard deviation, minimum and maximum values of the position deviation (meters from set point) and heading deviation shall be presented for all headings at the limiting wind speeds.

6.3.8

The maximum achievable DP capability number implies that the vessel can maintain positioning with all the DP capability numbers smaller than and equal to the maximum achievable.

6.3.9

The results shall be provided as wind envelope where the maximum achievable DP capability number and maximum achievable wind speed is produced for 360 degrees of environmental angles with a minimum of 10 degrees resolution.

Guidance note:

The results may also in addition be presented as thrust and/or power utilization envelopes as defined in Sec.2. These plots may show the average and/or the extreme values, and potentially also the standard deviations.

Results may also in addition be presented as position and/or heading deviations from setpoint, showing: average deviation and/or extremes values, and potentially also standard deviation. Other results may also be presented e.g.:

— Fuel consumption and emission envelopes: for a given design environmental condition the fuel consumption for maintaining station keeping and correspondent emission of air pollutants are given for each environment direction.
— Transient analysis after failures: this analysis provides the vessel footprint right after equipment failures, for example loss of one engine, an actuator or after the worst case single failure (loss of the most important redundancy group for each environment direction).

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.3.10

The performance of the whole simulator shall be documented by reporting the following simulator performance tests:

Vessel and thruster dynamics tests

The purpose of these tests is to check the actuator dynamic response (RPM rate, pitch rate, power rate, etc.) and the vessel response to actuator forces (mass and inertia properties, low speed resistance, etc.). The tests shall be performed with zero wind and current speeds, and zero wave height.

The following tests shall be run for a minimum of 2 minute each:

— From rest position, simulate full thrust ahead with all available thrusters to thrust in surge direction. The test shall be performed such that the yaw rate and sway velocity are negligible.
— From rest position, simulate full thrust backwards with all available thrusters to thrust in surge direction. The test shall be performed such that the yaw rate and sway velocity are negligible.
— From rest position, simulate full thrust starboard with all available thrusters to thrust in sway direction. The test shall be performed such that the yaw rate and surge speed are negligible.
— From rest position, simulate full thrust port with all available thrusters to thrust in sway direction. The test shall be performed such that the yaw rate and surge speed are negligible.
— From rest position, simulate full yaw moment clockwise with all available thrusters to create yaw moment. The test shall be performed such that the surge and sway speeds are negligible.
— From rest position, simulate full yaw moment counter-clockwise with all available thrusters to create yaw moment. The test shall be performed such that the surge and sway speeds are negligible.

  For each test, the following shall be presented as function of time:

  — surge, sway and yaw position and velocity
  — for each actuator: force, power, direction, rotational speed, pitch.

Environmental force tests

The purpose of these tests is to check the directions of the environmental forces acting on the vessel and how these affect the vessel when the vessel is not controlled by the DP control system. The following tests shall be performed with no DP control system enabled (free floating vessel).

The following tests shall be run for a minimum of 5 minutes each:

— With all thrusters disabled, zero wind speed and no waves, apply 1 m/s current speed at 0, 90, 180 and 270 degrees.

— With all thrusters disabled, zero current speed and no waves, apply 20 m/s wind speed at 0, 90, 180 and 270 degrees.
— With all thrusters disabled, zero wind and current speeds, apply 2 m of significant wave height (PM spectrum with T_z = 8 s) at 0, 90, 180 and 270 degrees.

  For each test, the following shall be presented as function of time:

  — surge, sway and yaw position and velocity
  — wind, current and wave loads and directions with respect to the vessel body-fixed coordinates.

DP Performance tests

The purpose of this test is to check the closed-loop dynamics for the vessel and DP control system. For these tests the DP control system shall be enabled and the vessel intact condition shall be used.

The following test runs shall be simulated for 30 minutes:

— For 0, 45 and 90 degrees of environmental direction, select wind, waves and current that gives an average total thrust utilization between 40% and 60%. Wind, current and waves shall be selected so that they provide approximately the same mean force.

  For each test, the following shall be presented as function of time:

  — position and heading deviation
  — actuators thrust and directions
  — wind, current and wave loads and directions.

6.4 Positioning limits

In DP capability level 3 a vessel is considered to maintain position if the low frequency position is less than 5 m from the setpoint and the heading is less than 3 degrees from the setpoint.

Figure 6-1 indicate a DP vessel footprint during station keeping simulations, and the corresponding position and heading limits.

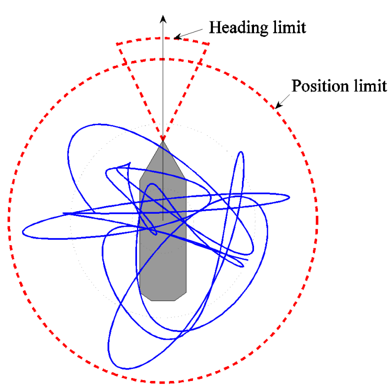

Figure 6-1 Position and heading limits

Guidance note:

If the low frequency position and heading are obtained from a filter, no frequencies below 0.04 Hz can be filtered out.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.5 Environment

6.5.1

The environment, including wave spectrum and directional spectrum, shall be the same as in DP capability level 1, as given in Table 2-1.

6.5.2

In DP capability level 3 calculations, the analysis shall assume infinite water depth.

6.6 Environmental loads

The DP capability level 3 capability shall be determined based on environment, loading condition and operating mode as defined in DP capability level 1. For vessels without a defined summer load line draft, the draft shall be the deepest approved operating draft.

6.7 Wind

6.7.1

Wind forces shall be determined based on model tests, RANSE simulations or other recognized methods. Validation reports shall be made available to the verifier on request. The validation report shall demonstrate the applicability and accuracy of the applied method in the actual application.

Guidance note:

Examples of recognized methods for wind load calculations are Blendermann's method and Isherwood's method.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.7.2

The mean wind load shall be compared to the level 1 method (when applicable) as function of heading for the DP capability level 1 B and D numbers. For DP capability level 3, the forces shall be computed with the vessel pinned to a fixed position and heading, see App.A.

6.7.3

The variation of wind speed (in time) around the average wind speed shall be modelled by a wind spectrum. The Frøya model spectral density shall be used. 1-min average wind speed at 10 m above sea level shall be used in the simulations. The mean wind speed shall be converted from 1-min (from the Beaufort weather scale) to 3-hours average. The correct wind speed shall also be used in the wind spectrum.

Guidance note:

Descriptions of wind spectra, wind speed conversions, and wind profiles may be found in DNV-RP-C205. The wind speed model is not required to include the variation of the mean wind speed with height above the ground (speed profile) when this effect is included in the wind coefficients.

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6.7.4

Projected areas for wind loads shall be computed from the DP capability level 1 method or from more accurate methods. A comparison of the wind areas with DP capability level 1 shall be provided.

6.8 Current

6.8.1

Current forces shall be determined based on model tests, RANSE simulations or other recognized methods. Validation reports shall be made available to the verifier on request. The validation report shall demonstrate the applicability and accuracy of the applied method in the actual application.

6.8.2

The mean current load shall be compared to the level 1 method (when applicable) as function of heading for the DP capability level 1 B and D numbers. For DP capability level 3, the forces shall be computed with the vessel pinned to a fixed position and heading, see App.A.

6.8.3

The current speed and direction shall be constant in one simulation.

6.8.4

For DP capability level 3, the current speed shall be assumed to be vertically uniformly distributed.

6.8.5

Projected areas for current loads shall be computed from the DP capability level 1 method or from more accurate methods. A comparison of the current areas with DP capability level 1 shall be provided.

6.9 Waves

6.9.1

Wave forces shall be determined based on model tests or CFD calculations (including potential theory). Validation reports shall be made available to the verifier on request. The validation report shall demonstrate the applicability and accuracy of the applied method in the actual application.

6.9.2

As a minimum the wave forces shall include slowly-varying drift forces, Froude-Kriloff forces and diffraction forces.

Guidance note 1:

See DNV-RP-C205. The wave-frequency load is also defined as the first-order wave load. A linear analysis is usually sufficiently accurate for prediction of wave-frequency loads and motion. Linear superposition may then be applied which means that the total load (or equivalent wave-frequency motion) may be computed as the sum of the contribution from each individual wave component in the sea state. The reader is referred to O. Faltinsen – *Sea Loads on Ships and Offshore Structures.*

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Guidance note 2:

Slowly-varying wave drift forces may be modelled employing quadratic transfer functions (QTF). Slowly-varying wave drift forces may also include wave drift damping forces.

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Guidance note 3:

For a detailed description of the theory see O. Faltinsen – *Sea Loads on Ships and Offshore Structures*. Most common models for computing the slowly-varying wave drift are: Newman's approximation and Full QTFs methods. The Newman method may be less computationally intensive, but typically provides less accurate results.

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6.9.3

Wind-generated waves shall be modelled by considering irregular waves with a directional wave spectrum. Details on the wave spectrum and its parameters, and number of wave components shall be documented and justified.

Guidance note:

See DNV-RP-C205. The number of frequencies to simulate a typical short term sea state should be selected such that the energy of the spectrum generated with the selected wave components is at least 95% of the total energy spectrum. A practical way to limit the number of wave components is to divide the wave frequency and direction sets in a grid, choose a random frequency and direction on each interval and then calculate the wave elevation from these. See O. Faltinsen – *Sea Loads on Ships and Offshore Structures.*

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6.9.4

The mean wave drift load shall be compared to the level 1 method (when applicable) as function of heading for the DP capability level 1 B and D numbers. For DP capability level 3, the forces shall be computed with the vessel pinned to a fixed position and heading, see App.A.

6.10 Actuators

6.10.1

Actuator forces shall be determined based on model tests or CFD (including potential theory) simulations. Validation reports shall be made available to the verifier on request. The validation report shall demonstrate the applicability and accuracy of the applied method in the actual application. The models shall, as minimum, include the effects from:

— propeller and motor dynamics
— angular rate limits for azimuth thrusters and rudders
— propeller pitch dynamics.

When requested, model parameters shall be documented and justified.

Guidance note 1:

Cycloid actuators can typically change the direction of the thrust faster than conventional azimuth thrusters. They may be treated as azimuth thrusters by implementing the corresponding dynamics for the force direction and magnitude rates of change. For this type of actuators, a typical value for 180 degrees force rotation may be 4 s.

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Guidance note 2:

For the calculation of the station-keeping performance, it may (depending on the level of detail wanted) be sufficient to represent the actuator dynamic effects by implementing a maximum rate of change for the propeller RPM/pitch, thruster azimuth and rudder angles.

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6.10.2

Thrust losses shall be determined based on empirical methods, model tests or CFD (including potential theory) simulations. When applying such methods, validation reports shall be made available to the verifier on request. The validation report shall demonstrate the applicability and accuracy of the applied method in the actual application.

6.10.3

Instantaneous thrust reduction due to thrust loss effects shall be accounted for. As a minimum, the following thrust loss effects shall be included:

— in-line losses due to relative water velocity
— cross-flow losses due to relative water velocity
— ventilation or aeration
— actuator-actuator interaction due to an actuator race towards other actuators
— actuator-hull interaction due to an actuator race towards hull sections such as pontoons, skeg, etc.
— coanda and blocking effects.

Guidance note 1:

The interaction may also include accounting for an actuator race towards a disabled actuator. This may typically be relevant after failure modes. Another relevant interaction may be the interaction between a stern tunnel thruster and main propellers.

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Guidance note 2:

Relative water velocity is caused by relative motion between actuator and water due to vessel motion, current, and wave-induced velocities. Other thrust loss effects may be due to fouling, anodes, ice or tunnel shape (e.g. lengths, opening, grid, hub).

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.10.4

Comparison of thrust and rudder forces, computed from DP capability level 1 and used for DP capability level 3 shall be documented (when applicable). See App.A for details on requirements. Significant discrepancies between the results from DP capability level 3 and DP capability level 1 shall be justified.

6.11 Vessel dynamics

6.11.1

Vessel motions shall be described by equations of motion and, as a minimum, contain 3 degrees of freedom: surge, sway and yaw.

Guidance note:

For operability analyses involving the evaluation of other vessel states such as heave, roll and pitch motions, equations of motion for 6-degrees of freedom should be implemented.

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6.11.2

The equations of motion shall as a minimum include:

— vessel mass and inertia
— frequency dependent added mass
— frequency dependent potential damping
— wind forces
— current forces
— wave forces
— actuator forces.

In addition, depending on operation and system formulation, the following shall be included in the equations of motion:

— restoring forces
— coriolis and centripetal forces (both inertia and added mass).

Guidance note 1:

For a thorough description of the environmental variables the reader is referred to DNV-RP-F205. The equations of motion for a freely floating or moored structure may be written as:

$$\boldsymbol{M}\ddot{\boldsymbol{x}} + \boldsymbol{B}\dot{\boldsymbol{x}} + \boldsymbol{D_1}\dot{\boldsymbol{x}} + \boldsymbol{D_2}\boldsymbol{f}(\dot{\boldsymbol{x}}) + \boldsymbol{K}\boldsymbol{x} = \boldsymbol{q}(t, \boldsymbol{x}, \dot{\boldsymbol{x}})$$

where

$\boldsymbol{M}$ = mass matrix, $\boldsymbol{m}+\boldsymbol{A}(\omega)$, including added mass.
$\boldsymbol{m}$ = structural mass matrix
$\boldsymbol{B}$ = potential damping matrix $\boldsymbol{B} = \boldsymbol{B}(\omega)$
$\boldsymbol{D_1}$ = linear damping matrix, including wave drift damping
$\boldsymbol{D_2}$ = quadratic damping matrix
$\boldsymbol{f}$ = vector function where each element is given by $x_i|x_i|$
$\boldsymbol{K}$ = position-dependent hydrostatic stiffness matrix
$\boldsymbol{x}$ = position vector
$\boldsymbol{q}$ = exciting force vector

The exciting force on the right hand side is

$$\boldsymbol{q}(t, \boldsymbol{x}, \dot{\boldsymbol{x}}) = \boldsymbol{q}_{WA}^{(1)} + \boldsymbol{q}_{WA}^{(2)} + \boldsymbol{q}_{CU} + \boldsymbol{q}_{WI} + \boldsymbol{q}_{ext}$$

where

$\boldsymbol{q}_{WA}^{(1)}$ = first order wave excitation force

$\boldsymbol{q}_{WA}^{(2)}$ = second order wave excitation force

$\boldsymbol{q}_{CU}$ = current drag force

$\boldsymbol{q}_{WI}$ = wind drag force

$\boldsymbol{q}_{ext}$ = any other forces (specified forces and forces from station-keeping and coupling elements, etc.)

Coriolis and centripetal forces (both inertia and added mass) have also to be included when the equations of motion are given in an accelerated coordinate system such as a vessel body-fixed reference frame.

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Guidance note 2:

The motion dynamics of the vessel may be modelled as superposition of a low-frequency and a wave-frequency model or as a unified model:

— With the low-frequency and wave-frequency vessel motion modelled separately, the total vessel motion is obtained by summing the low-frequency and wave-frequency motion. The wave-frequency motions may be computed combining waves with motion response amplitude operators (RAOs). The low-frequency motion is computed from the equations of motion defined in [6.11.2] without considering the wave- frequency load as input since its effect on the motion is added separately. In this case the added mass $A(\omega) = A(0)$ and the frequency depending hydrodynamic damping $B(\omega) = 0$.

— When considering the unified model, the wave-frequency loads have also to be included in the equations of motion defined in [6.11.2]. The wave-frequency forces and moments may be computed from the force RAOs. The motion and force RAOs may be obtained from commercial software based on model tests and CFD. In this formulation, the frequency dependent added mass and damping are typically accounted for by use of retardation functions. See DNV-RP-F205 for further details.

For description of low-frequency and wave-frequency motion implementation, the reader is also referred to: Fossen – *A nonlinear unified state-space model for ship maneuvering and control in a seaway.*

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6.12 Sensors

6.12.1

Position reference systems and sensors used in DP operations shall be included to simulate their main characteristics.

6.12.2

Main characteristics such as typical noise values and delays shall be included.

6.13 DP control system

6.13.1

A DP control system utilizes measurements to compute actuator commands to control the vessel position and heading.

6.13.2

The DP control system may be either the vessel specific DP control system software from the DP control system vendor, or a mathematical model. The vendor DP control software setting and version shall correspond to the actual vessel when available. The vendor DP control system software version and the simulator version shall be specified as applicable.

Guidance note:

Results are highly dependent on the tuning of the DP control system in the simulator. When comparing results with different DP control systems, one should be aware that the result obtained with a DP control system tuned to fit the simulator performance is likely to be better than when using the vessel specific DP control software settings.

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6.13.3

When the vendor DP control system software is not used, the DP control system model shall include, as minimum, a control module, a thrust allocation module, and a filter or observer. The DP control system implementation shall in this case be documented and all parameters specified.

Guidance note:

Typical control laws are implemented as wind feed-forward and proportional-integral-derivative (PID) actions:

$$\tau_c = \tau_{FF} + \tau_{PID}$$

Where τ_C is the output of the control module in surge, sway and yaw, τ_{FF} is the wind feed-forward action and τ_{PID} the PID action.

The wind feed-forward action is for directly counteract wind loads and may be implemented as

$$\tau_{FF} = -0.8 \cdot \tau_{wind}$$

Where τ_{wind} is the estimated force and moment loads from wind.

The PID control law is typically implemented as

$$\tau_{PID} = -K_P x_{LF} - K_1 \int x_{LF}\, dt - K_D v_{LF}$$

Where K_P, K_I, K_D are PID controller gains, x_{LF} is estimated position/heading deviation from setpoint, and v_{LF} is the estimated velocity.

Filters are typically implemented by combining the measurements from position reference systems and sensors and vessel model dynamics into a Kalman filter or state observer.

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6.14 Filter/observer

In the mathematical model, the filter/ observer shall process the measured signals from position reference systems and sensors to estimate the vessel position and velocity (including wave frequent motion), low frequency vessel position and velocity, and wave frequent vessel motion.

6.15 Control module

6.15.1

The control module shall process the set-points and the estimated vessel positions and velocities from the filter/observer and calculate control forces.

6.15.2

Power limitations and black out prevention shall be included in the DP control system module.

Guidance note:

The power to the actuators is typically limited to 90 - 95% of the installed power.

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6.16 Thrust allocation

6.16.1

The thrust allocation takes the control forces from the control module as input and distributes them to the actuators.

Guidance note:

The primary objective of a thrust allocation algorithm is to compute a control input to the actuators that ensures that the commanded force and moment (from the control module) to maintain station keeping are produced by the actuators at all time. This objective may fail to be met if the commanded forces and moment require forces beyond the capabilities of the actuators due to saturation or other physical limitations. Usually, some kind of priority is involved such that the primary objective may be represented as an optimization problem. Other objectives may be defined in the thrust allocation algorithm. Often, these are chosen from an operational perspective in order to minimize power or fuel consumption, minimization of actuator/effector tear and wear, or other criteria. Actuator constraints such as actuator rate constraints and forbidden zones may be included in the formulation. For further information about different types of thrust allocation, the reader is referred to *T. A. Johansen, T. I. Fossen, Control Allocation – A Survey, Automatica, Vol. 49, pp 1087-1103, 2013*.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

6.16.2

The thrust allocation shall include forbidden sectors and power limitations.

6.16.3

Handling of thrust saturation shall be included in the DP control system module.

6.17 Power generation and distribution

6.17.1

Power generation, distribution, loads, load sharing and power management functions shall be simulated in order to capture the main characteristics of the power plant that influence the vessel station-keeping performance. As a minimum the following shall be included:

— generator and engine power generation rate limitations
— electrical losses, both transmission, motor and generator losses
— load sharing and load limitations including blackout prevention.

Guidance note:

Electrical losses for machinery usually vary with current, so at each load the losses may be different. The electrical loss factor may be chosen for high power load condition and employed also for low loads.

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6.17.2

When simulating transients in the power system (e.g. transients after failures) the following additional effects shall be included:

— load dependent start and stop of generators.

6.17.3

Simulations shall be in accordance with the vessel power consumption balance. This shall be evaluated and documented in the report. The power reserved for hotel and consumers not part of the thruster system shall be documented.

Guidance note:

Other power loads included in the simulations may for example be drilling loads and fire-fighting pump loads.

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6.17.4

The use of limited energy sources like e.g. batteries in the DP capability assessment shall follow the requirements in DP capability level 2. The power flow and energy level shall be simulated.

6.17.5

The single line diagram and description of the power distribution and generation shall be provided. This includes the load sharing philosophy.

SECTION 7 DP CAPABILITY LEVEL 3-SITE

7.1 Objective

7.1.1

The purpose of DP capability level 3-site is to get more insight on the vessel's DP capability performance by use of time-domain simulations for a specific location and operation. Simulations are performed with a vessel model controlled by a DP control system which may or may not be the same control system supplied by the DP control system maker. By performing time-domain simulations and including the relevant dynamics, DP capability level 3-site may provide more information about the station keeping performance than the other DP capability levels, such as statistics of the vessel position and heading, thruster and power utilization, and of other relevant vessel states.

7.1.2

The purpose of DP capability level 3-site is to assess the effect of dynamics on the DP performance. Relevant dynamics are:

— vessel dynamics
— environmental load dynamics
— actuators dynamics
— external force dynamics
— DP control system dynamics.

7.1.3

DP capability level 3-site is designed to assess the DP capability in operation and site specific conditions.

7.2 Application

7.2.1

The method described in this section is valid for all vessel shapes.

7.2.2

When both DP capability level 3 and DP capability level 3-site are computed, the results from DP capability level 3-site shall coincide with DP capability level 3 results if the same analysis method, operating mode, load condition, positioning limits and environmental condition are used.

Guidance note:

This means that the same methodology is used for DP capability level 3 and DP capability level 3-site. E.g. in case the DP capability level 3-sites calculations uses the Thorsethaugen wave spectrum, then DP capability level-3 must use the PM spectrum (as for DP capability level 1) but otherwise the same methodology as when calculating DP capability level 3-site, i.e. the same equations.

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7.3 Analysis method for DP capability level 3-site

7.3.1

DP capability level 3-site shall be computed based on the analysis method for DP capability level 3 with the additional requirements stated in this section.

7.3.2

The vessel shall be considered in station keeping if it can maintain position and heading within the limits for at least 3 simulated hours for a given environmental condition.

Guidance note:

The simulated time-window for each wave realization may be adjusted, for 3 hours and up, based on the operational needs. Statistics of position and heading (and other vessel states) for shorter time-windows inside the total simulation time-window may also be provided.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

7.3.3

Simulation sampling time shall be fast enough to capture vessel dynamics including vessel motion, actuator systems, sensors, power generation and DP control system dynamics, as well as relevant effects of environmental and other external load dynamics.

7.3.4

In DP capability level 3-site, the simulations shall be representative for the considered operational and site environmental conditions.

7.4 Positioning limits for DP capability level 3-site

7.4.1

The position limits shall be chosen according to the specific requirements of the operation considered.

Guidance note 1:

Depending on the operation positioning requirements, the vessel total motion or the low frequency motion can be used to check if the position limits are exceeded.

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Guidance note 2:

If the low-frequency position and heading are obtained from a filter, no frequencies below 0.04 Hz can be filtered out when these are used to check the position limits.

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Guidance note 3:

Additional criteria, such as operational limits (heave, roll and pitch motion limits for example), may also be included in the analysis. In such cases the resulting limiting wind speeds will have to satisfy both the station keeping criteria as well as the operational criteria. This analysis will then be defined as an operability analysis.

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7.4.2

The operational and environmental conditions shall be specified in the DP capability level 3-site report.

7.5 Environment

In DP capability level 3-site calculations, the user is free to choose the environment. In addition to level 1 and level 2 environmental variables the most relevant environmental variables for a DP analysis are:

— wind, waves and current may not be collinear
— other combinations of wind speed, current speed, wave height and wave period
— different wave spectrum and wave spreading
— swell
— wind spectrum and profile
— current speed profile
— shallow water.

Guidance note:

For a thorough description of the environmental conditions, see DNV-RP-C205.

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7.6 Environmental loads

The user is free to define the loading condition and operating mode of the vessel, including but not limited to draft, trim, and projected areas.

7.7 Wind

Wind forces shall be computed according to DP capability level 3.

7.8 Current

7.8.1

Current forces shall be computed according to DP capability level 3 with the additional requirements stated in [7.8.2].

7.8.2

For DP capability level 3-site, the current speed profile over the water depth shall be implemented when this can significantly affect the external load or the current load on the hull.

Guidance note 1:

For example, external loads due to drilling risers are highly affected by the current speed profiles. For a thorough description of the environmental variables the reader is referred to DNV-RP-C205.

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Guidance note 2:

Other environmental effects that may have an impact into the station keeping performance are: upwellings, rip currents, solitary waves or solitons and extreme waves.

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7.9 Waves

Wave forces shall be determined based on DP capability level 3 methodology. In addition the effect of the water depth shall be included.

7.10 Actuators

Propulsion forces shall be determined based on DP capability level 3 methodology. In addition the effect of the water depth shall be included.

Comparison of thrust and rudder forces, computed from DP capability level 1 and used for DP capability level 3-site shall be documented (when applicable). See App.A for details on requirements. Significant discrepancies between the results from DP capability level 3-site and DP capability level 1 shall be justified.

7.11 External forces

DP capability level 3-site calculations may include external forces from e.g. pipe-laying, risers, mooring lines, offshore loading hoses and hawsers. The external forces included in the simulations shall be documented in the report.

7.12 Vessel dynamics

The vessel motions shall be described by equations of motion as for DP capability level 3.

7.13 Sensors

7.13.1

Position reference systems and sensors used in DP operations shall be included according to DP capability level 3.

7.13.2

In addition DP capability level 3-site may include the effect of the operational limitations of position reference systems. Description on these limitations and how the position reference systems are configured and handled in the DP control system shall be provided.

Guidance note:

Operational limitations of position reference systems may include range/sector of relative position reference systems, satellite shadow areas for GNSS due to site structures, etc.

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7.14 DP control system

The requirements for a DP control system, filter, control module and thrust allocation requirements are the same as for DP capability level 3.

7.15 Power generation and distribution

The requirements for the power generation, distribution, loads and PMS simulation are the same as for DP capability level 3.

APPENDIX A DP CAPABILITY REPORTING

A.1 General

This appendix states requirements for reporting DP capability results. The information in the report shall as far as practicable be given in the same sequence as requested in the following paragraphs.

A.2 General requirements

A.2.1

The report shall start with a front page including, as minimum, the following information:

— document title
— document date
— author(s) name, company and contact information.

A.2.2

The report shall include an executive summary stating, as a minimum, the following information:

— vessel name/project identification
— vessel main particulars
— identification of the DP capability standard used for the calculation (name and edition of the standard)
— main conclusion including DP capability numbers and plots as required for the different DP capability levels
— identification of DP redundancy groups (actuators and power generation) and WCSF design intent (actuators and power generation) when required.

A.2.3

A figure showing the reference frame and coordinate system shall be included. The coordinate system shall be defined as in [2.8.2].

A.2.4

A list of references shall be included in an appendix.

A.2.5

The report shall contain, as minimum, the following elements:

— front page
— executive summary
— list of abbreviations and symbols
— reference frame and coordinate systems
— environmental conditions
— vessel description (vessel name, type) and DP design philosophy
— method, model description and input documentation used for the calculation
— description of each calculated case with results (runs)
— appendices.

Guidance note:

Vessel description should also include IMO number, new build number, yard name, class society identification, etc., when available.

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A.2.6

Reporting for DP capability level 2, level 2-site, level 3 and level 3-site shall follow the requirements for reporting for DP capability level 1. Any difference from DP capability level 1 on the applied calculation method shall be justified and documented. Such differences shall be clearly stated early in the report under a separate heading. Parameters requested in level 1 tables may not be applicable for some vessel designs. In such cases these parameters should be set as not applicable (NA) in the corresponding tables.

A.3 Requirements for DP capability level 1

A.3.1

The executive summary shall include the following plots:

— Vessel in its intact condition (no failures). An example is given in Figure A-1.

In addition for redundant systems:

— Combined plot with the lowest result for each heading across all the redundancy groups. An example is given in Figure A-1.
— Combined plot with the results from all redundancy groups. An example is given in Figure A-2.
— A table including the DP capability results in DP capability number scale for each heading. An example for few heading is given in Table A-4.

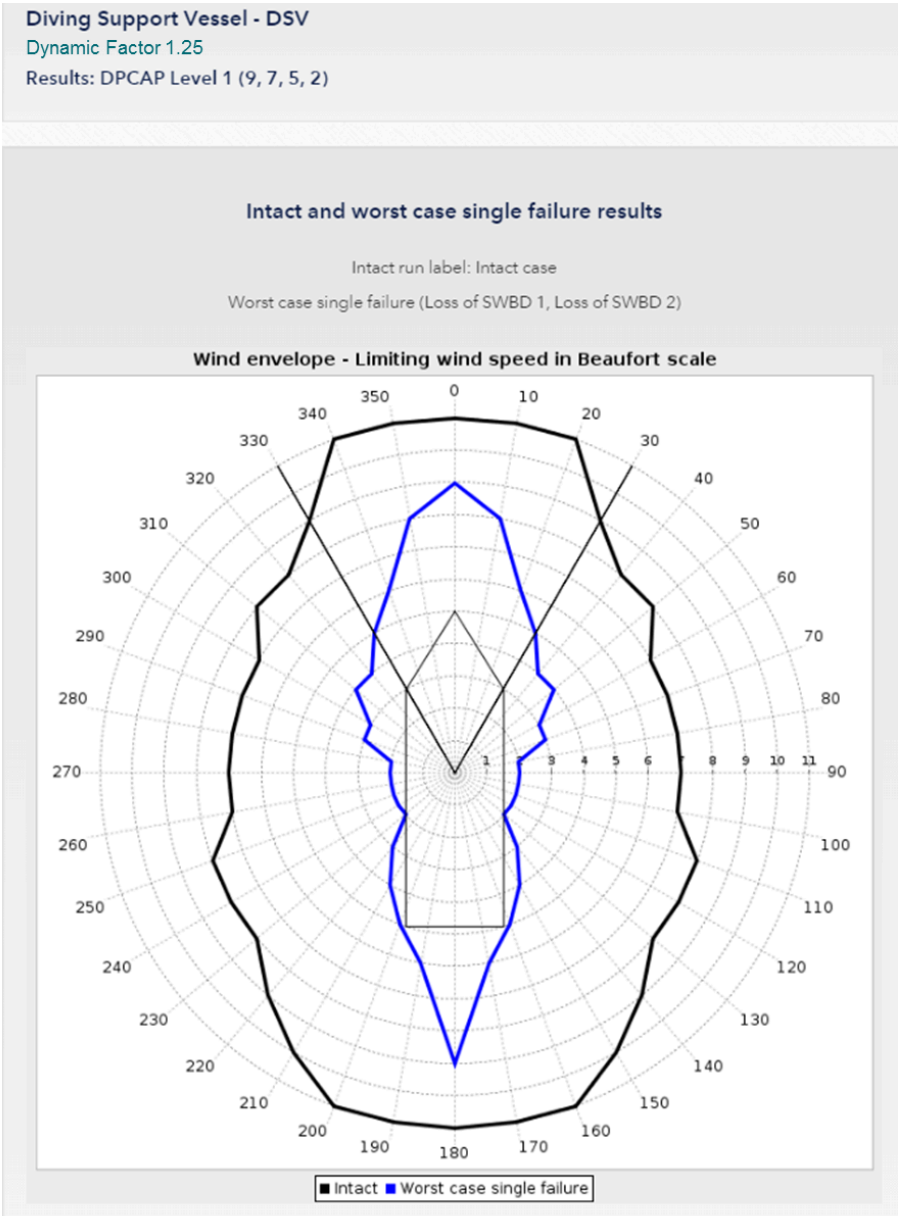

Figure A-1 Example of a DP capability plot for level 1 including the intact condition and a combined plot for the WCSF.

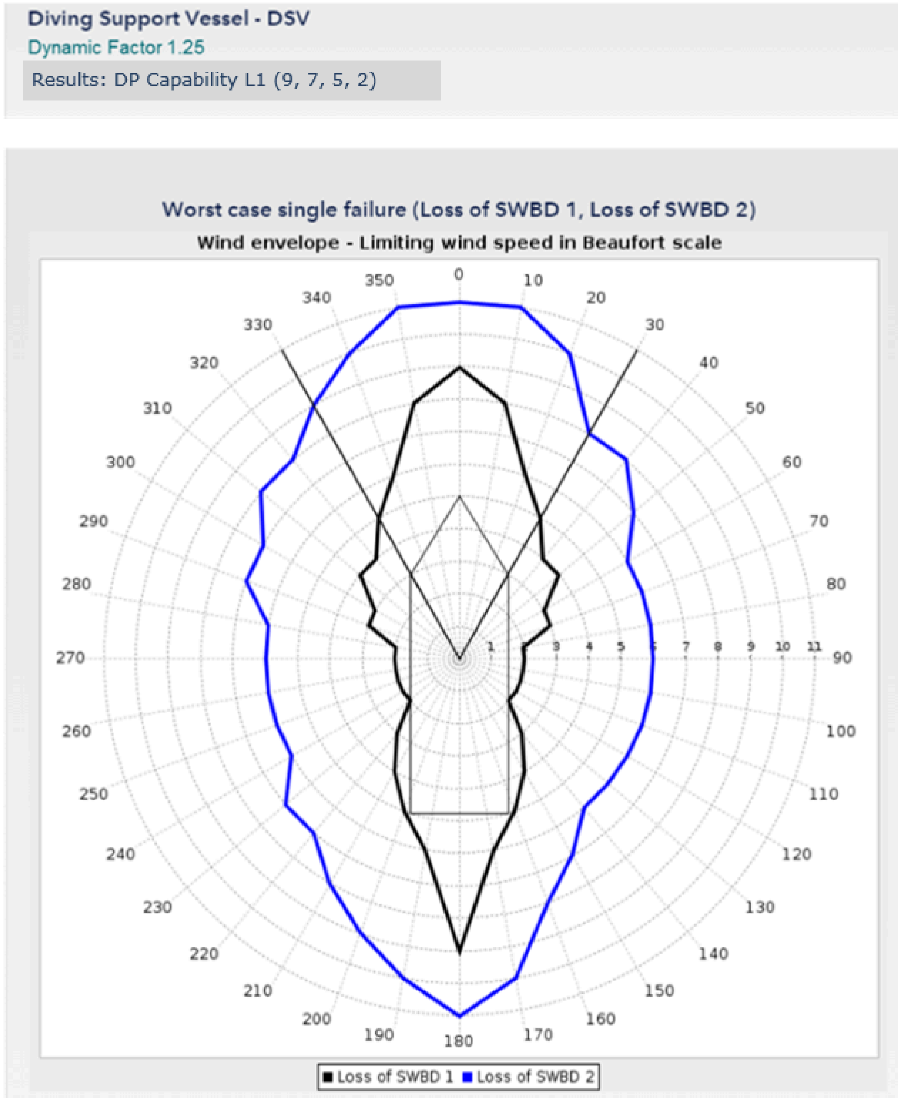

Figure A-2 Example of a DP capability plot for level 1 for the failure conditions.

Table A-1 Example of a DP capability level 1 results – DP capability number scale

Heading [deg]	*Intact case*	*Loss of SWBD 1*	*Loss of SWBD 2*
0	11	9	11
10	11	8	11
20	11	6	10
30	9	5	8

A.3.2

The reference frame and coordinate system may be included as a figure. An example is given in Figure A-3.

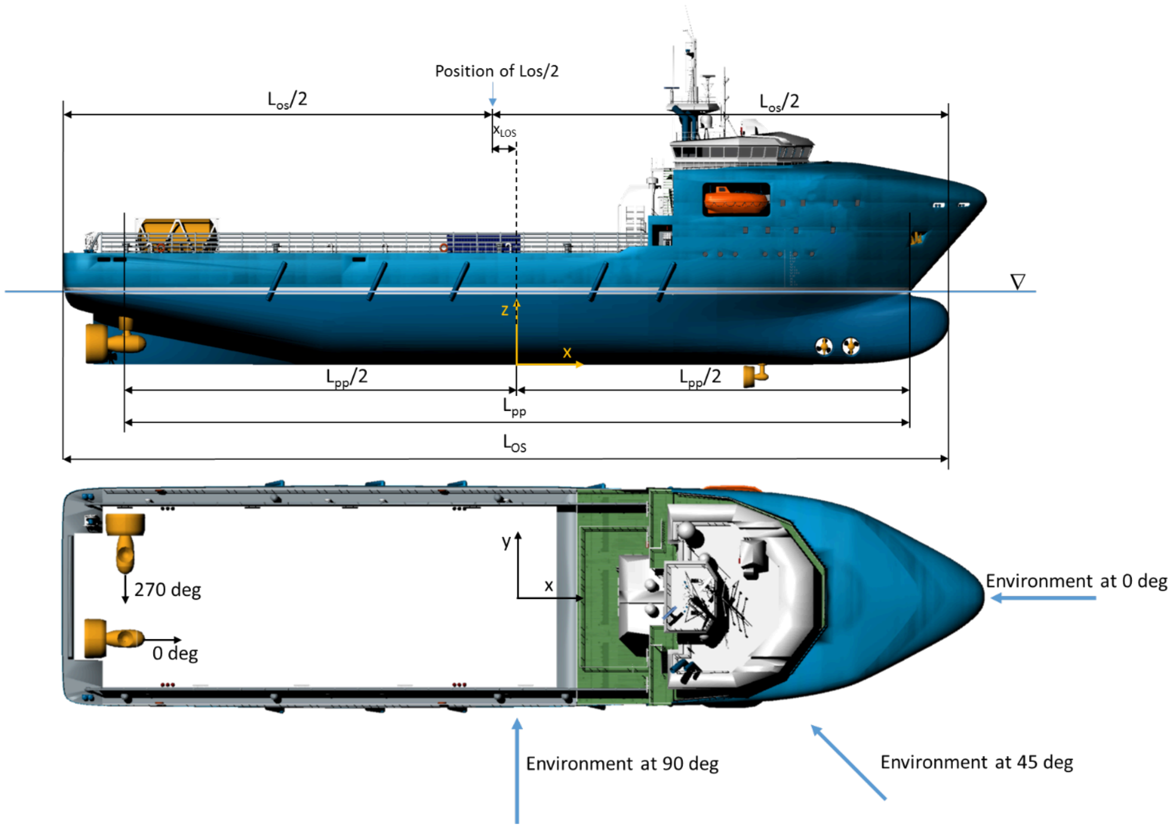

Figure A-3 Example of a reference frame and coordinate system figure.

A.3.3

The DP capability number table, as presented in Table 2-1, shall be included.

A.3.4

Input documentation to the calculations shall, as a minimum, be documented as follows:

— general arrangement (showing the vessel with its equipment in the position used as basis for the calculations)
— hull data according to Table A-2
— actuator data according to Table A-3
— when rudders are part of the DP systems, then also Table A-4 shall be submitted
— power system single line diagram
— power generation and distribution description including electrical power consumption balance.

Table A-2 Hull data

Description	*Unit*	*Parameter*
Length over all	[m]	L_{OA}
Length between perpendiculars	[m]	L_{pp}
Summer load line draft	[m]	draft
Maximum breadth at water line	[m]	B
Distance between the foremost and aftmost point on the hull below the free surface at summer load line draft even keel	[m]	L_{os}
Longitudinal position of $L_{os}/2$	[m]	X_{Los}
Bow angle	[rad]	bow_{angle}
Water plane area behind $L_{pp}/2$	[m^2]	A_{WLaft}
Surge position of aftmost point on skeg 1	[m]	X_{skeg1}
Sway position of aftmost point on skeg 1	[m]	Y_{skeg1}
Surge position of aftmost point on skeg 2	[m]	X_{skeg2}
Sway position of aftmost point on skeg 2	[m]	Y_{skeg2}
Projected transverse area (projected in sway-heave plane) above water	[m^2]	$A_{F,wind}$
Projected longitudinal area (projected in surge-heave plane) above water	[m^2]	$A_{L,wind}$
Surge position of area centre of the projected longitudinal area above water with respect to $L_{pp}/2$	[m]	$X_{L,air}$
Projected transverse area (projected in surge-heave plane) below water	[m^2]	$A_{F,current}$
Projected longitudinal area (projected in surge-heave plane) below water	[m^2]	$A_{L,current}$
Surge position of area centre of the projected longitudinal area below water with respect to $L_{pp}/2$	[m]	$X_{L,current}$

Table A-3 Actuator data

Parameter	*Thr. 1*	*Thr. 2*	*Thr. 3*	*Thr. 4*	*Thr. 5*	*Thr. 6*	*Thr. 7*	*Thr. 8*	*Thr. 9*	*Thr. 10*
Maker's name										
Maker's thruster type (identification)										
Max. power consumption in DP/ bollard pull, i.e. with torque and power limitations [kW]										
Propeller diameter [m]										
Type of actuator (shaft line, azimuth, pod, tunnel thruster, water jet, cycloid)										
Fixed pitch (FPP) or controllable pitch (CPP) propeller										
Is ducted (yes/no)										
Is a permanent magnet thruster (yes/no)										
Is contra rotating (yes/no)										
Tunnel inlet shape (broken, rounded, other) according to Table 3-2										
Thruster x-position [m]										
Thruster y-position [m]										
Thruster z-position [m]										
Nominal thrust [kN]										
Parameters in **bold** are output from the computations.										

Table A-4 Rudder data

	Rudder 1	*Rudder 2*	*Unit*
Profile type			-
Rudder area directly behind the propeller, A_r			[m^2]
Rudder coefficient k_1			-
Rudder coefficient k_2			-
Maximum rudder angle			[deg]
Maximum side force from rudder			**[kN]**
Parameters in **bold** are output from the computations.			

A.3.5

Each run (calculated condition) shall include, as a minimum, the following documentation:

— Run name.
— DP system setup and operating mode description (power and thruster configuration, which thruster/generator/prime mover is on/off, set-up of other major consumers, power reserved for hotel and consumers not part of the thrusters).
— Thruster power configuration providing in a table how much power each thruster can consume from each switchboard and/or prime mover. An example is given in Table A-5.
— Forbidden zones drawing or table. See Figure A-4 and Table A-6 for an example.
— Wind envelope polar plots with DP capability number scale and m/s scale.
— A table with the run results including, as minimum, environmental direction (or heading) with a minimum 10 degree resolution, limiting DP capability number, limiting wind speed, wind, current and wave forces. An example for few headings is given in Table A-7.
— A table with the run results including, as minimum, 0-360 degrees environmental direction (or heading) with a minimum 10 degree resolution, limiting DP capability number, thruster direction, thrust utilization before thrust losses (% or in force unit), thrust loss factor, rudder angle, rudder F_{surge} and F_{sway}, and thruster power utilization P. An example for few headings is given in Table A-8.
— A table with the run results including, as minimum, 0-360 degrees environmental direction (or heading) with a minimum 10 degree resolution, limiting DP capability number, thruster individual power consumption for each switchboard and Prime movers directly connected to propellers. An example for few headings is given in Table A-9.
— A table with the run results including, as minimum, 0-360 degrees environmental direction (or heading) with a minimum 10 degree resolution, limiting DP capability number, Power utilization for each switchboard (% of max available and in power unit), power reserved for hotel and consumers not part of the thrusters. An example for few headings is given in Table A-10.

Guidance note:

Additional plots such as thrust and power utilization plots should be presented in the run sections.

Table A-5 Thruster power configuration

Thruster ID	*SWBD 1*	*SWBD 2*	*PM1*	*PM2*	*PM3*	*PM4*
THR 1	100%	-	-	-	-	-
THR 2	-	100%	-	-	-	-
THR 3	100%	-	-	-	-	-
THR 4	-	-	100%	-	-	-
THR 5	-	-	-	100%	-	-
Dynamic factor	Type: Wind, current and wave load factor			Value: 1.25		

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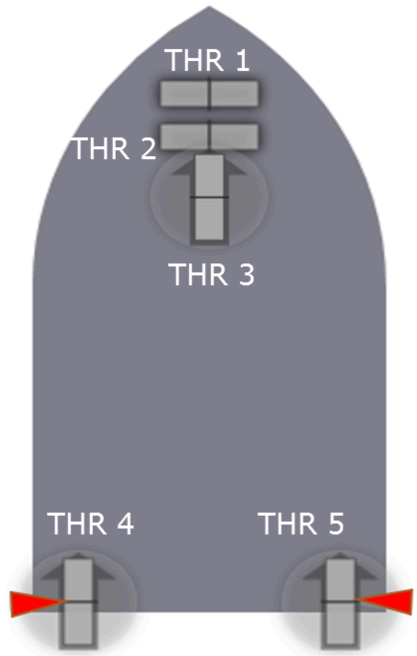

Figure A-4 Forbidden zones marked with red. The zones indicated refer to the thrust-vector.

Table A-6 Thruster forbidden zone

Thruster ID	*Zone 1 [degrees]*	
THR 1	-	-
THR 2	-	-
THR 3	-	-
THR 4	80	100
THR 5	-100	-80

Table A-7 Station keeping capability results

Heading [deg]	*DP capability #*	*Wind speed [m/s]*	*Current force [kN]*	*Current moment [kNm]*	*Wave force [kN]*	*Wave moment [kNm]*	*Wind force [kN]*	*Wind moment [kNm]*
0								
10								
20								
30								

Table A-8 Thruster utilization results

Heading [deg]	*DP capability #*		*Thr 1*	*Thr 2*	*Thr 3*	*Thr 4*	*Thr 5*	*Rudder 1*	*Rudder 2*
0		Thr direction/ rudder angle [deg]							
		Utilization %							
		Thr force [kN]							
		Rudder F_{surge} [kN]							
		Rudder F_{sway} [kN]							
		Thrust loss factor							
		Power utilization [kW]							
10		Thr direction/ rudder angle [deg]							
		Utilization %							
		Thr force [kN]							
		Rudder F_{surge} [kN]							
		Rudder F_{sway} [kN]							
		Thrust loss factor							
		Power utilization [kW]							
20		Thr direction/ rudder angle [deg]							
		Utilization %							
		Thr force [kN]							
		Rudder F_{surge} [kN]							
		Rudder F_{sway} [kN]							
		Thrust loss factor							
		Power utilization [kW]							
30		Thr direction/ rudder angle [deg]							
		Utilization %							
		Thr force [kN]							
		Rudder F_{surge} [kN]							
		Rudder F_{sway} [kN]							
		Thrust loss factor							
		Power utilization [kW]							

Table A-9 Thruster individual power utilization results [kW]

Heading [deg]	*DP capability #*		*Thr 1*	*Thr 2*	*Thr 3*	*Thr 4*	*Thr 5*
0		SWBD 1					
		SWBD 2					
		PM1					
		PM2					
		PM3					
		PM4					
10		SWBD 1					
		SWBD 2					
		PM1					
		PM2					
		PM3					
		PM4					
20		SWBD 1					
		SWBD 2					
		PM1					
		PM2					
		PM3					
		PM4					
30		SWBD 1					
		SWBD 2					
		PM1					
		PM2					
		PM3					
		PM4					

Table A-10 Power utilization results at the switchboard level

Heading [deg]	*DP capability #*		*SWBD 1*	*SWBD 2*
0		DP Power available – P_B [kW]		
		Power reserved [%, kW]		
		Power utilized [%, kW]		
10		DP Power available – P_B [kW]		
		Power reserved [%, kW]		
		Power utilized [%, kW]		
20		DP Power available – P_B [kW]		
		Power reserved [%, kW]		
		Power utilized [%, kW]		
30		DP Power available – P_B [kW]		
		Power reserved [%, kW]		
		Power utilized [%, kW]		

A.3.6

The runs shall be given in the following sequence:

— vessel in its intact condition (no failures)
— each redundancy group (for redundant systems)
— other additional capability plots, if any.

Guidance note:
Additional calculated conditions for other DP capability 'levels' required by the standard should be placed in an appendix, e.g. DP capability level 2 and DP capability level 1 when the intended "level" is DP capability level 2-site.

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A.3.7

As a minimum the following information shall be specified on each plot:

— vessel name
— DP capability result when applicable
— type of plot and caption
— dynamic factors
— vessel condition (e.g. intact, loss of specific thruster or WCSF)
— the units.

A.4 Requirements for DP capability level 2

A.4.1

Reporting for DP capability level 2 shall follow the requirements for reporting for DP capability level 1. Any difference from DP capability level 1 on the applied calculation method shall be justified and documented. Such differences shall be clearly stated early in the report under a separate heading.

A.4.2

Additional input data used for the calculation shall be provided by extending the input data descriptions and tables in section [A.3].

A.5 Requirements for DP capability level 2-site

A.5.1

Reporting for DP capability level 2-site shall follow, as a minimum, the requirements for reporting for DP capability level 1 apart from the fact that the limiting wind speed shall be presented in m/s. Any difference from DP capability level 1 on the applied calculation method shall be justified and documented.

A.5.2

Additional input data used for the calculation shall be provided by extending the input data descriptions and tables in section [A.3].

A.5.3

Description and input data of external forces shall be provided when external forces are included in the calculation.

A.5.4

Description and input data for the site specific environmental conditions shall be provided. An example is given in Table A-11.

Table A-11 Environmental conditions

Wind	*Wave and wave spreading*	*Current*	*Swell*
Wind speed Wind directions	Significant wave height Zero-crossing period Wave spectrum and its parameters Wave directions Spreading function	Wind induced current speed Tidal current speed Current directions Current profile over depth	Significant swell height Zero-crossing period Swell spectrum and its parameters Swell directions

A.6 Requirements for DP capability level 3

A.6.1

Reporting for DP capability level 3 shall follow the requirements for reporting for DP capability level 1 with the additional requirements stated in this section.

A.6.2

Additional input data used for the calculation shall be provided by extending the input data descriptions and tables in section [A.3].

A.6.3

A topology drawing of the simulation setup shall be provided. An example is given in Figure A-5.

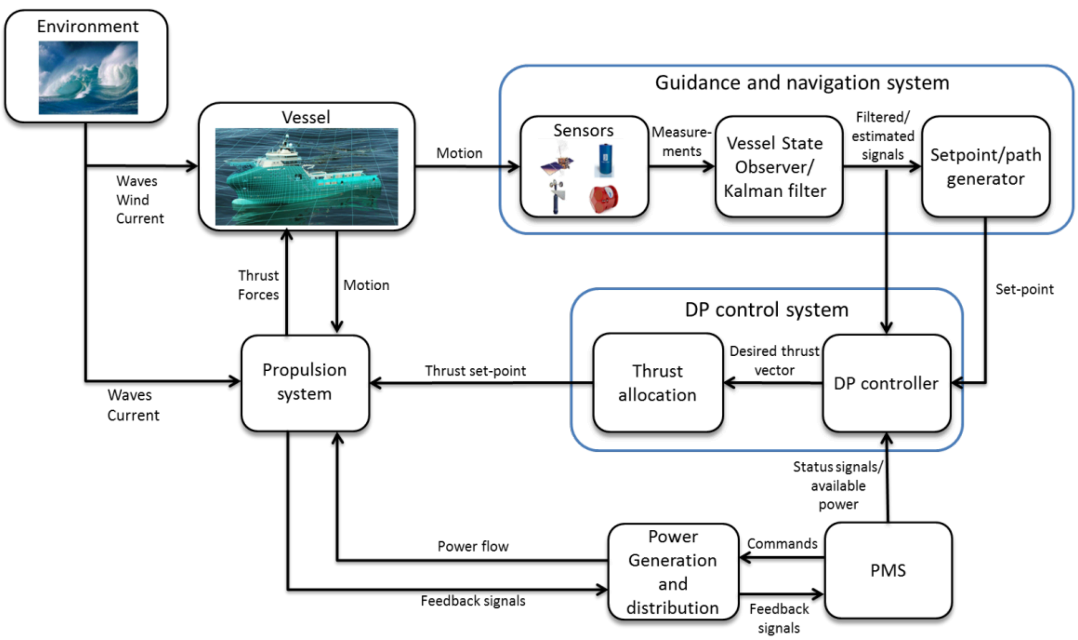

Figure A-5 Example of a simulation setup for DP capability level 3

A.6.4

The simulation sampling time(s) shall be justified and documented.

A.6.5

The number of wave realizations that are simulated for each considered case shall be provided. An example is given in Table A-12.

Table A-12 DP capability level 3 – Simulations parameters

Sampling time	[s]
Number of wave realizations for each run	
Positioning limits	5 m
Heading limits	3 deg
Vessel motion used to check the positioning	Low frequency motion
Simulated hours for checking the vessel positioning against the limits	3 hours

A.6.6

Description of the wind, current and wave force models and parameters shall be documented.

A.6.7

Description and input data for the environmental conditions shall be provided. An example is given in Table A-13.

Table A-13 Environmental conditions

Wind	*Wave and wave spreading*	*Current*	*Swell*
Wind speed Wind directions Wind spectrum	Significant wave height Zero-crossing period Wave spectrum and its parameters Wave directions Spreading function Number of wave components	Wind induced current speed Tidal current speed Current directions Current profile over depth	Significant swell height Zero-crossing period Swell spectrum and its parameters Swell directions

A.6.8

Description of the actuator models, including their dynamics, and the model parameters shall be provided. As a minimum, the implementation of the following shall be described:

— propeller and rudder force curves
— propeller and motor dynamics
— angular rate limits for azimuth thrusters and rudders
— propeller pitch dynamics.

A.6.9

Description of the models implemented for the actuator thrust losses shall be provided.

Guidance note:

The thrust loss models may be documented, in addition to a description, by presenting the following plots. The thrust loss effects should be enabled one at the time:

— In-line losses due to relative water velocity: plotting the 4-quadrant CT, CQ or KT, KQ propeller thrust and torque coefficient curves.
— Cross-flow losses due to relative water velocity: plotting the maximum thrust in DP as function of the water velocity, for a water flow coming from 90 degrees with respect the propeller rotational axis.
— Ventilation or aeration; effect of free surface elevation: plotting the maximum thrust in DP as function of the propeller relative submergence (z/D, z is the actuator vertical position as defined in [2.8.2] and [3.8]).
— Actuator-actuator interaction due to an actuator race towards other actuators (the vessel is pinned to a fixed position):
  — Plotting the maximum thrust in DP of the affected actuator as function of the race direction of the source actuator. The source actuator should produce maximum thrust in DP.
  — Plotting the maximum thrust in DP of the affected actuator as function of its race direction when flushing a dead thruster.
— Actuator-hull interaction due to an actuator race towards hull sections such as pontoons, skeg, etc.: plotting the maximum thrust in DP of the affected actuator as function of its direction for 360 degrees (10 degree spacing – the vessel is pinned to a fixed position).

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A.6.10

Description of the vessel equations of motion shall be provided, see section [6.11] for an example.

A.6.11

Description of position reference systems and sensor models and parameters used in simulations shall be provided. As a minimum, the main characteristics such as typical noise values and delays shall be provided.

A.6.12

Description of the DP control system model and its parameters shall be provided. It shall be clearly stated if the employed DP control system is the vessel specific DP control system software from the DP control system vendor, or a mathematical model.

Guidance note:

Typical documentation should include:

— control law implementation and gains
— filter implementation, cut-off frequencies, gains, etc.
— set point/path generation implementation
— thrust allocation optimization, handling of saturation, actuator rate limits, forbidden zones and power limitations.

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A.6.13

The vendor DP control system software version or the simulator version shall be documented based on what is used in the simulation setup.

A.6.14

Description of the power system generation and distribution model and its parameters shall be provided. As minimum the following shall be documented:

— generator and engine power generation rate limitations

— electrical losses, both transmission, motor and generator losses
— load sharing and load limitations including blackout prevention.

A.6.15

Any power loads included in the simulations shall be documented.

A.6.16

Results from each run shall follow, as a minimum, the requirements for DP capability level 1 where the results shall be presented with limiting wind speed in m/s. When presenting the results on environmental loads, thruster forces and power consumption (Table A-7, Table A-8, Table A-9 and Table A-10), minimum, maximum, average and standard deviation values shall be presented as a minimum. Thrust utilization may be presented as average value.

A.6.17

Average values, standard deviation, minimum and maximum values of the position deviation (meters from set point) and heading deviation shall be presented for all headings at the limiting wind speeds. An example is given in Table A-14.

Table A-14 Position and heading deviation statistics

Heading [deg]	*DP capability #/ limiting wind speed [m/s]*	*Position deviation [m]*				*Heading deviation [deg]*			
		Mean	Std	Min	Max	Mean	Std	Min	Max
0									
10									
20									

Heading [deg]	DP capability #/ limiting wind speed [m/s]	Position deviation [m]				Heading deviation [deg]			
30									

A.6.18

The performance of the whole simulator shall be documented by reporting the simulator performance tests described in [6.3.10].

A.7 Requirements for DP capability level 3-site

A.7.1

Reporting for DP capability level 3-site shall follow the requirements for reporting for DP capability level 3 in addition to the requirements included in this section.

A.7.2

Table A-12 shall be filled in with the relevant site specific parameters such as positioning limits, which motion is used to check the vessel positioning against the positioning limits, length of each simulations, other considered operating limits, water depth, etc.

A.7.3

The results limiting wind speed shall be presented in m/s unit.

A.7.4

Description of the external force models and input data shall be provided when external forces are included in the calculation.

A.7.5

Description and input data for the site specific environmental conditions shall be provided. An example is given in Table A-11.

APPENDIX B USAGE OF THE DIFFERENT DP CAPABILITY LEVELS

B.1 Guideline for usage of the different DP capability levels

B.1.1 Typical use of different DP capability levels

The information provided by the different DP capability levels has inherent different properties. The user of DP capability information shall ensure that the information provided by the chosen method/level is suitable for the intended use. Table B-1 provides an example overview of typical usage of different DP capability levels.

Table B-1 Typical use of different DP capability levels

DP Capability Level	*Examples on typical use*	*Typical value for users*
Level 1	— High level DP capability assessment (not suitable for detailed vessel design). — Vessel benchmarking.	— Prescriptive method: consistent and comparable results. — Improve decision input for vessel selection. — Free Web-App available on Veracity.com. — Easy to deliver class required DP capability assessment numbers.
Level 2	— When vessel specific parameters are important.	— Take advantage of equipment/vessel specific performance. — For other hull shapes then mono hulls.
Level 2-site	— When site specific environmental conditions are important. — When operation specific vessel load condition is important. — When external forces are important.	— Allow for use of site specific weather and to take in to account external forces. — Preliminary operational planning.
Level 3	— When more information on vessel position and heading performance is wanted. — When vessel and equipment dynamics are important (e.g. position, heading or other motion in other degrees of freedom, thruster/power dynamics, gangway motion, etc.).	Designers and yards: — Right size vessels, realistic fuel consumption calculation and operability. — Battery sizing. Operators: — Benchmarking vessel positioning and heading performance. DP vessel owners: — Supporting documentation on operational capabilities in different modes (e.g. normal and degraded modes).

DP Capability Level	*Examples on typical use*	*Typical value for users*
Level 3-site	— When more information on vessel performance is wanted (e.g. planning of and vessel selection for critical operations, site specific analysis and inclusion of external forces). — When the vessel position and heading needs to be estimated for specific environmental conditions and operation. — When vessel and equipment dynamics are important (e.g. position, heading or other motion in other degrees of freedom, thruster/power dynamics, gangway motion, etc.).	Designers and yards: — Right size vessels, realistic fuel consumption calculation and operability. — Battery sizing. Operators: — Better data for choosing the right vessel for specific operations in a specific environment. — Improved planning, improved operating limits – improved risk control. DP vessel owners: — Operational and contingency planning. — Supporting documentation on operational capabilities in different modes (e.g. normal and degraded modes) and under different (e.g. environmental) conditions.

B.2 Guidance on specifying DP capability analyses for different levels

B.2.1 General

The purpose of this subsection is to provide some guidance to the users on writing specifications for DP capability analyses. Table B-1 may provide help to the user on selecting the most appropriate DP capability level based on project needs and intended use. Based on the chosen level, the user may then specify the requirements for the analysis. [B.2.2] to [B.2.6] provide examples of specification for DP capability analyses for different levels. This subsection also contains guidance on what should not be requested for each level based on the experience the Society has gained since the standard was first published. When necessary, project specific adjustments should be made to the below specifications.

B.2.2 DP capability level 1

Example specifications:

— The DP capability plots and numbers shall be presented in form of wind envelopes (limiting wind speed for given environmental direction) according to this standard - level 1.

Guidance note:

The list below shows some typical requirements which cannot be included in a specification for a level 1 analysis. In case some of listed requirements are needed, a different level must be requested.

— site-specific environmental conditions
— addition power loads (e.g. power load from industrial mission equipment) on the switchboards other than the prescribed 10%
— current, wind and waves not from the same direction
— other draft than summer load line draft
— external forces from drilling risers, mooring lines, pipes, etc.
— vessel position footprints
— deviations from the prescriptive formulas.

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B.2.3 DP capability level 2

Example specifications:

— The DP capability plots and numbers shall be presented in form of wind envelopes (limiting wind speed for given environmental direction) according to this standard - level 2.
— The calculation shall be performed with zero forward speed, summer load line draft, even keel. For vessels without a defined summer load line draft, the draft shall be the deepest approved operating draft.
— The calculation shall be performed with wind, current, and wave drift coefficients specific to the vessel.
— The calculation shall be performed with project specific reserved power for electrical losses, hotel loads, and other loads not related to actuators.
— The calculation shall be performed with actuator losses according to the vessel and actuator specific equipment.

Optional specifications:

— Results may also be presented as thrust and power utilization for the limiting environmental conditions.

Guidance note:

The list below shows some typical requirements which cannot be included in a specification for a level 2 analysis. In case some of listed requirements are needed, a different level must be requested.

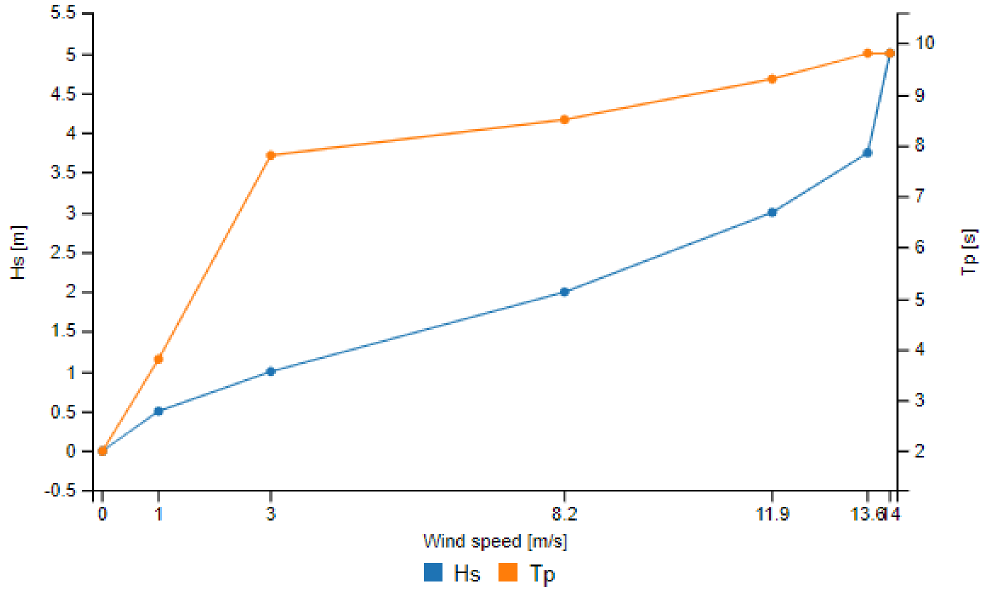
— site-specific environmental conditions
— current, wind and waves not from the same direction
— other draft than summer load line draft for mono-hulls
— external forces from drilling risers, mooring lines, pipes, etc.
— vessel position footprints.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

B.2.4 DP capability level 2-Site

Example specifications:

— The DP capability plots shall be presented in form of wind envelopes (limiting wind speed for given environmental direction) according to this standard - level 2 site.
— The wind envelopes shall be calculated for the specific site: *site name* A example table with wind speed, wave height and wave period is given below. Wind and waves shall be collinear. Current speed shall be set to 0.5 m/s with direction collinear with wind and waves. The wave spectrum shall be JONSWAP with $\cos^2$ directional spreading function and gamma = 3.3.
— The calculation shall be performed with the following load condition: *draft name*, *draft* m, *trim angle* deg.
— The calculation shall be performed with wind, current, and wave drift coefficients specific to the vessel.
— The calculation shall be performed with project specific reserved power for electrical losses, hotel loads, and other loads not related to actuators.
— The calculation shall be performed with actuator losses according to the vessel and actuator specific equipment.
— External forces from *Specify Forces (drilling riser, pipe, hawser, etc.)* shall be included in the analysis.



wind speed	Hs	Tp
0	0	2
1	0.5	3.8
3	1	7.8
8.2	2	8.5
11.9	3	9.3
13.6	3.75	9.8
14	5	9.8

Figure B-1 Example of wind-wave relationship.

Optional specifications:

— Results shall also be presented as thrust and power utilization for given environmental conditions.

Guidance note:

The list below shows some typical requirements which cannot be included in a specification for a level 2-site analysis. In case some of listed requirements are needed, a different level must be requested.

— DP capability numbers

— vessel position footprints.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

B.2.5 DP capability level 3

Example specifications:

— The DP capability plots and numbers shall be presented in form of DP capability numbers and wind envelopes (limiting wind speed for given environmental direction) according to this standard - level 3.
— The calculation shall be performed with zero forward speed, summer load line draft, even keel. For vessels without a defined summer load line draft, the draft shall be the deepest approved operating draft.
— The calculation shall be performed with wind, current, and wave drift coefficients specific to the vessel.
— The calculation shall be performed with actuator dynamics and thrust losses according to the vessel and actuator specific equipment.
— Simulations shall be in accordance with the vessel power consumption balance.
— The positioning limits shall be 5 metre and 3 degrees. Simulations lengths shall be 3-hours. As minimum three (3) wave realizations shall be simulated.
— The calculations shall be performed considering the low-frequency vessel motion when assessing the vessel positioning against the positioning limits.

Optional specifications:

— Results may also be presented as thrust and power utilization, vessel motion and footprints, environmental forces, individual thruster forces and angles for limiting environmental conditions.

Guidance note:

The list below shows some typical requirements which cannot be included in a specification for a level 3 analysis. In case some of listed requirements are needed, a different level must be requested.

— site-specific environmental conditions
— current, wind and waves not from the same direction
— other draft than Summer load line draft for mono-hulls
— external forces from drilling risers, mooring lines, pipes, etc.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

B.2.6 DP capability level 3-site

Example specifications:

— The DP capability plots shall be presented in form of DP capability numbers and wind envelopes (limiting wind speed for given environmental direction) according to this standard - level 3-site.
— The wind envelopes shall be calculated for the specific site: *site name* A example table with wind speed, wave height and wave period is given in Figure B-1. Wind and waves shall be collinear. Current speed shall be set to 0.5 m/s with direction collinear with wind and waves. The wave spectrum shall be JONSWAP with $\cos^2$ directional spreading function and gamma = 3.3.
— The calculation shall be performed with the following load condition: *draft name*, *draft* m, *trim angle* deg.
— The calculation shall be performed with wind, current, and wave drift coefficients specific to the vessel.
— The calculation shall be performed with actuator dynamics and thrust losses according to the vessel and actuator specific equipment.
— Simulations shall be in accordance with the vessel power consumption balance.
— The positioning limits shall be specific to the specified operation: 10 m and 5 degrees for position and heading respectively. Simulations lengths shall be 3 hours. As minimum five (5) wave realizations shall be simulated.
— The calculation shall be performed considering either the low-frequency motion when assessing the vessel positioning against the positioning limits.
— External forces from *specify forces (drilling riser, pipe, hawser, etc.)* shall be included in the analysis.

Optional specifications:

— Results may also be presented as thrust and power utilization, vessel motion and footprints, environmental forces, individual thruster forces and angles for given environmental conditions.

Guidance note:

The list below shows some typical requirements which cannot be included in a specification for a level 3-site analysis. In case some of listed requirements are needed, a different level must be requested.

— DP capability numbers.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

CHANGES – HISTORIC

March 2018 edition

Changes March 2018, entering into force as from date of publication

Topic	*Reference*	*Description*
Updating of DP capability assessments based on industry feedback	[A.2.6]	Parameters requested in level 1 tables may not be applicable for some vessel designs. It is now specified that in such cases these parameters should be set as not applicable (NA) in the corresponding tables.
	Table C-1	Guidance on the typical application of the different levels is provided.
	Table 1-2	Definition of L_{pp} (length between perpendiculars) is updated to also cover non ship shaped vessels.
	[2.5.1]	Definition of the DP capability result string is clarified and rewritten.
	[2.9.2]	Requirements for the verification of the DP capability analyses are improved by adding also a check on the actuator and environmental forces as these are required to be included in the analysis report.
	Table 2-2	It is clarified that for level 2 and level 3 calculations, for vessels without a defined summer load line draft, the draft shall be taken as the deepest approved operating draft. (This is also reflected in paragraphs [4.5], [6.3.1] and [6.6].)
	[3.7]	As some vessel may result in the water plane area coefficient outside the validity range of the level 1 method, it has been defined that values outside the valid range will be set equal to the maximum (or minimum) allowed value in the range.
	[3.9.2]	For contra-rotating pods with one propeller in each end of the pod house, the propeller diameter to be used in the calculation is defined as the diameter of the largest propeller.
	[3.9.4]	The definition of the propeller submergence has been clarified. A formula is now provided.
	[3.11.5]	New and improved formula for calculation of losses due to interaction between a thruster race and a skeg. The new formula replaces the requirement for thrust forbidden zones toward skegs.
	[3.9.2]	The efficiency factor for cycloidal actuators has been increased from 850 to 900. This was done after reviewing additional documentation for such actuators.
	[5.4]	For level 2-site analyses the standard now suggests to use 1-min average wind speed.

Topic	*Reference*	*Description*
	[5.9]	By running hydrodynamics calculations, it was found that the formulation to derive thrust losses due to propeller ventilation can be used also with the JONSWAP wave spectrum and directional wave spreading from 2 to 8.
	[6.3.10]	The level 3 simulator test requirements have been improved by clarifying the reasons for testing. DP set-point change test is removed and replaced by a station keeping test requirement.
	[6.7.3]	For level 3-site analyses the standard now suggests to use 1-min average wind speed.

July 2016 edition

This is a new document.

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