DNV·GL

CLASS GUIDELINE

DNVGL-CG-0131 Edition July 2019

Strength analysis of hull structure in container ships

DNV GL AS

FOREWORD

DNV GL class guidelines contain methods, technical requirements, principles and acceptance criteria related to classed objects as referred to from the rules.

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

CHANGES – CURRENT

This document supersedes the January 2018 edition of DNVGL-CG-0131.

Changes in this document are highlighted in red colour. However, if the changes involve a whole chapter, section or subsection, normally only the title will be in red colour.

Changes July 2019

Topic	*Reference*	*Description*
Introduction of class notation **RSD** for small container vessels	Sec.1 Table 1	Reduced scope for ships with $L \leq 230\ m$.
	Sec.1 [6]	Reduced scope with a reference to DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8.
	Sec.2 [1.3.3]	Explanations for application of the static torsion moment.
	Sec.2 [1.5.1]	Requirements are updated with reference DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8.
	Sec.2 [1.5.2]	Requirements are updated with reference DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8.The abbreviation ULS is deleted to avoid confusion.
	Sec.2 Table 2	Requirements for the consideration of the static torsion moment are updated.
	Sec.2 Table 3	Consideration of the static torsion moment. Correction of the rolling conditions.
	Sec.2 [1.5.5]	Clarified requirements and referred to DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8.

Editorial corrections

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

CONTENTS

SECTION 1 INTRODUCTION

1 General

This class guideline (CG) should be considered in connection with DNV GL Rules for Classification of Ships, DNVGL-RU-SHIP Pt.3 *Hull* and DNVGL-RU-SHIP Pt.5 Ch.2 Sec.1 *Container Ships*.

This CG describes the scope and methods required for structural analysis of container ships and the background for how such analyses should be carried out. The description is based on relevant rules for classification of ships.

The DNV GL rules for classification of ships may require direct structural strength analyses in case of a complex structural arrangement, or unusual vessel size.

Structural analyses carried out in accordance with the procedure outlined here and in DNVGL-CG-0127 *Finite Element Analysis* will fulfil the requirements to calculations as required by the rules.

Where the text refers to the rules for classification of ships, the references refer to the latest edition of the rules for classification of ships.

2 Container ship characteristics

2.1 Container ship categories

Container ships are ships designed for the transportation of container cargoes and arranged with cell guides in holds. Containers are standardised in several sizes, e.g. 20’, 40’, 45’ and 48’ containers are common. The most common sizes are 20’ (TEU: Twenty-foot equivalent unit) and 40’ (FEU: Forty-foot equivalent unit) containers. The size of the container ship will be influenced by the characteristics of the route and trade pattern for which the ship is operating. The ships may be categorised as follows according to the size group:

— *Feeder container ship*: A container ship which can carry approximately 100 TEU- 3.000 TEU and is mainly deployed for short voyages between hub ports and small ports in the local area. The ships may be equipped with cranes for serving smaller ports where gantry cranes are not available.
— *Panamax*: A container ship which can carry up to about 5.500 TEU. Main dimensions are limited to the Panama Canal (B = 32.2 m, Loa = 294 m, T = 12.0). Ballast requirements to maintain acceptable stability are a concern of the Panamax due to its high length to beam ratio.
— *Post-Panamax*: A container ship exceeding the Panama Canal limits. Post-Panamax container ships typically have a capacity greater than 5000 TEU.
— *NPX, New Panamax:* A container ship with dimensions allowing it to pass the new Panama Canal locks, with Loa = 366 m, B = 49 m and T = 15.2, with a size of 12.500 – 14.500TEU.
— Ultra large container ships (ULCS): designs exceeding the NPX limits. The biggest container ships deployed have continuously increased in size over the decades.

2.2 Operational patterns that may have impact on the design

Container ships are normally operated on regular routes between designated ports. The time schedule is extremely important for the operation of container ships. The weather and sea conditions vary, depending on where the ship is trading.

Variations in the loading conditions will also affect the behaviour of the ship at sea, making it complex to predict the actual long-term loading on the hull structure.

This classification guideline focuses on typical load combinations established to prevent structural problems during regular trade around the world.

Ship owners and operators, if they have specific knowledge about possible loading conditions, trade routes, preferred *GM* values during operation etc., should give such information to the designers in shipyards and class as early as possible when planning a new project. By providing such information, the amount of assumptions made during the construction phase may be reduced, giving increased confidence in the validity of the design calculation.

2.3 Torsion response

Container ships having large hatch openings are subject to large torsion response compared to ships having closed cross-sections. Only considering the vertical hull girder force components is therefore not sufficient to decide the required hull girder strength.

The torsion (wave torsion induced by oblique wave encounter) and the horizontal wave bending moment should therefore also be included in the hull girder strength assessments.

The criticality of the torsion response will heavily depend on the ship size. This CG describes two different levels for longitudinal hull girder strength assessments including torsion analysis as shown in Table 1.

3 Objectives

The objective of this classification guideline is:

— To give a guidance for design and assessment of the hull structures of container ships in accordance with the rules for classification of ships
— To give a general description on how to carry out relevant calculations and analyses
— To suggest alternative methods for torsion response calculation
— To achieve a reliable design by adopting rational design and analysis procedures.

4 Application and scope

4.1 Overview of different analysis levels

In order to achieve the objectives described in [3], two different analysis levels are defined. The two different analysis levels are applicable for the design of container ships according to the vessel characteristics as described in Table 1.

Level 1 analysis must be carried out as part of the mandatory procedure for the class approval for all container ships.

Findings from the more comprehensive level 2 analysis may result in additional strengthening.

Table 1 Analysis levels versus calculation/analysis scope

	Level 1	*Level 2*
Applicable Notation	**Container ship**	**RSD**
Mandatory scope of calculation/analysis	— hull girder strength calculation and local rule scantlings — rule check of hull girder ultimate strength — rule fatigue strength calculation for longitudinal end connections and selected details of upper hull — cargo hold analysis based on rule-defined loading conditions.	
Supplementary scope of analysis		Global FE analysis with EDW's from direct wave load analysis

	Level 1	*Level 2*
Remarks	Suitable for ships up to Panamax size and with conventional design for which the Society and designer have experience	Required for large ships and/or novel design Required with full analysis scope for ships with L > 230 m Optional with reduced analysis scope for ships with $L \leq 230\ m$

5 Mandatory scope of calculation/analysis, Level 1

5.1 Rule check of hull girder strength and local scantlings

Longitudinal strength of the vessel and local scantlings must be verified by the rule-defined calculation procedure as described in DNVGL-RU-SHIP Pt.3 Ch.5 under consideration of vertical & horizontal bending and torsion moments and vertical & torsional shear forces. Hull Section Scantlings shall be utilised for a suitable number of cross-sections along the length of the ship. Special attention should be given to sections where the arrangement of longitudinal material changes. Sections close to the aft and forward quarter-length and at the transition between the engine room and cargo hold area need to be specially considered.

5.2 Rule check of hull girder ultimate strength

A ultimate hull girder criterion is given in DNVGL-RU-SHIP Pt.3 Ch.5 Sec.4. This implies that the whole length of the ship is verified to have sufficient ultimate hull girder strength to resist an extreme vertical wave hogging moment without suffering hull girder collapse.

5.3 Rule fatigue strength calculation for longitudinal end connections

For container ships it is mandatory (see DNVGL-RU-SHIP Pt.5 Ch.2 Sec.7 [1.1.2]), to assess the fatigue characteristics of longitudinal end connections and of selected details in the upper hull using the prescriptive method as given in DNVGL-CG-0129 *Fatigue assessment of ship structures*.

5.4 Cargo hold analysis based on rule-defined load cases

Strength of primary structural members particularly in way of the double bottom, is to be assessed through a cargo hold analysis for the midship area as specified in DNVGL-RU-SHIP Pt.5 Ch.2 Sec.6 [2] and in DNVGL-CG-0127 *Finite Element Analysis*.

For typical fuel oil deep tank arrangements, i.e., tanks are below the deck house in a twin-island design or tanks are below one 40’ container bay in a single-island design, an additional strength analysis must be carried out in order to determine the required scantling of primary structures. For deep tanks inside a double skin transverse bulkhead the strength is to be presented by the cargo hold analysis for midship area.

6 Scope for Level 2 global analysis

A Level 2 global analysis includes a FE model covering the entire ship length, typically modelled with girder spaced mesh or alternatively with a stiffener spaced mesh. The objective is to obtain a reliable description of the overall hull girder stiffness and to calculate and assess the global stresses and deformations of all primary hull members for specified load cases resulting from realistic loading conditions and equivalent design waves determined by direct wave load analysis. In particular the scantlings of members which are influenced mainly by the torsional moment, i.e. the radii of the hatch corners as well as face plates and horizontal girders of the transverse bulkheads, shall be checked by a global analysis.

For the full analysis scope following global response evaluation is to be carried out over the entire ship length:

— Yield check of nominal stresses in way of all structural members as required in DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8 [3.7.1].
— Buckling check due to bi-axial nominal stresses of all structural members as required in DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8 [3.7.2].
— Fatigue assessment of hatch corners and other welded details as required in DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8 [3.5] and DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8 [3.6].
— Assessment of hatch opening deflections and hatch cover movements, as guidance to the hatch cover manufacturer, see Sec.2 [3].

In case of an optional global analysis for container ships with $L \leq 230\ m$ a reduced scope shall be applied in accordance with DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8 [3].

SECTION 2 LEVEL 2 GLOBAL ANALYSIS

1 EDWs from direct wave load analysis

1.1 General

Equivalent design waves are determined by a wave load analysis to calculate hull girder forces and moments corresponding to the rule requirements. The numerical simulation of wave and acceleration forces ensures a realistic superposition of the different hull girder load components.

1.2 Loading conditions

The required loading conditions for level 2 global analysis are given in DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8 [3.2] for strength and fatigue assessment.

1.3 Mass model

The inertia loads and external pressures need to be in equilibrium in the global FE-analysis, keeping the reaction forces at a minimum. The sum of local loads along the hull needs to give the correct global response as well as local response for further stress evaluation. Since the inertia and wave pressures are obtained and transferred from the hydrodynamic analysis, using the same mass-model for both structural analysis and hydrodynamic analysis ensure consistent load and response between structural and hydrodynamic analysis.

This means that the mass-model used need to ensure that the motion characteristics and load application is properly represented.

In the hydrodynamic analysis the mass needs to be correctly described to obtain correct motions and sectional forces, while global/local stress patterns are affected by the mass description in the structural analysis. The mass modelling therefore should represent the relevant loading condition from the trim and stability booklet., i.e. have the same:

— total weight
— centre of gravity in longitudinal, vertical and transverse direction
— radius of gyration for roll and pitch.

Experience shows that the hydrodynamic analysis will give some small modification to the total mass and centre of gravity, where the buoyancy is decided by the draft and trim of the loading condition in question.

Each loading condition analysed needs an individual mass-model. The lightship weight components such as hull structure, machinery and equipment, outfitting, etc. are consistent for all models, but other weight groups such as cargo, ballast water and fuel oil is different from one loading condition to another.

To obtain the correct mass-distribution in the FE model, an iteration process for tuning the mass distribution has to be carried out in the initial phase of the load application.

1.3.1 Light ship weight

Light weight is defined as the weight that is fixed for all relevant loading conditions, e.g. steel weight, equipment, machinery, etc. The steel weight of the hull structure is obtained by applying a material density to the FE-elements. Missing steel weight for structural components not included in the model can be represented by nodal masses or by an increased material density for the modelled structural members. To match a specified centre of gravity position for the hull structure weight, different material densities can be used for the individual element groups.

The remaining lightship weight such as machinery, hatch covers, outfitting, etc. will be represented by a nodal masses in relevant regions. According to extent and centres of gravity of the different weight components the masses are to be distributed on the corresponding nodes. The use of negative nodal masses is not acceptable. The whole mass model shall be in compliance with the considered lightship weight distribution from the trim and stability booklet.

1.3.2 Water ballast and tank contents

For small tanks it is sufficient to represent the liquid mass by distribution of nodal masses to the surrounding structure.

For greater tanks such as deep fuel oil and water ballast tanks it is necessary to apply the local pressure distribution on the tank boundaries.

1.3.3 Container loads

For the container forces following assumptions are to be included:

- Centre of gravity for every container is to be assumed at 45% of the container height.
- No explicit wind force needs to be considered for deck containers.
- The number of tiers in each stack based on the specification in the trim and stability booklet for the relevant loading condition.
- The container masses shall be redistributed between starbord and portside in each bay, such that the required static torsion moment, as given in DNVGL-RU-SHIP Pt.3 Ch.4 Sec.4 [2.3], is achieved over the entire cargo hold region(s).

The inertia forces of the containers have to be transferred to appropriate nodes at structural intersections considering the following:

- Deck container loads should be applied to the hull structure as concentrated forces at X, Y and Z stoppers of hatch covers. Alternatively the hatch cover geometry can be disregarded and all load components will be applied at the 40’ container corners into the transverse coaming. In case of 20’ containers an appropriate distribution of the forces into the coaming in front and behind the 40’ bay, as shown in Figure 1, must be considered. For simplification the vertical forces may be assumed as a uniform distributed line load along the transverse hatch coamings instead of the concentrated loads.
- For deck containers with direct fixation on deck or stanchions all load components are to be applied at the 20’ or 40’ container corners.
- The tipping moment induced by deck containers accelerated in longitudinal or transverse direction must be considered by corresponding z-forces at the vertical contact points into the hull structure, see Figure 2.
- For containers in holds the vertical forces are transferred into the inner bottom at the corner points of 20’ or 40’ containers.
- For 40’ hold containers in hold, the transverse and longitudinal forces are to be applied to the transverse bulkhead members in way of the cell guide.
- For 20’ hold containers loaded in 40’ bays, it is assumed that 1/3 of the total transverse force is transferred into inner bottom in the middle of the hold at the free end of the 20’ containers. At the other container end at top and bottom corners the remaining 2/3 of the total transverse force are to be applied to the transverse bulkhead members in way of the cell guide. Longitudinal forces are to be applied to the transverse bulkhead members in way of the cell guide.

The load transfer can be carried out in different ways:

- direct application on the ship interface nodes according to the definitions above
- use of temporary beams between the container mass points and the ship interface nodes
- use of auxiliary systems to account for the containers itself during the calculation of the global FE-model itself.

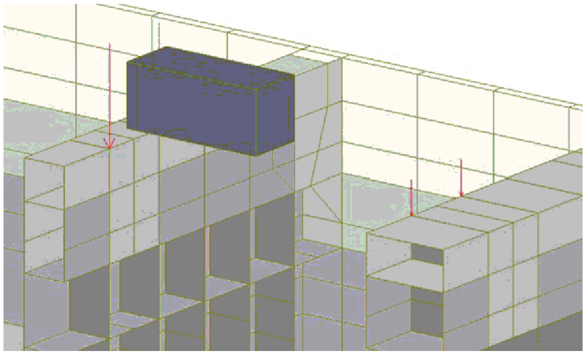

Figure 1 Forces of a vertical accelerated 20’ deck container

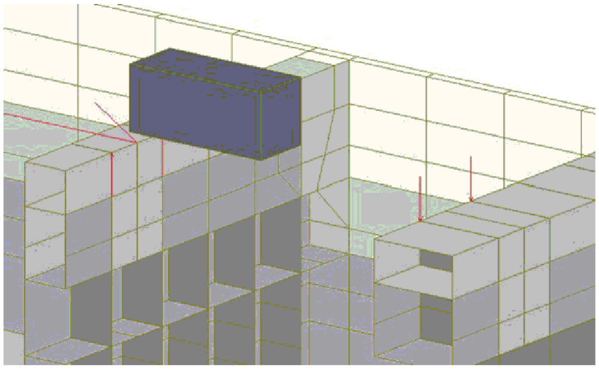

Figure 2 Forces of a longitudinal accelerated 20’ deck container

If auxiliary systems are used for load application and load transfer, they shall not influence the stiffness of the global FE model. This shall be checked by test calculation without loads on the auxiliary systems. Deformations of the hull have to result into stresses and strains within the auxiliary systems equal to zero. On-deck containers can be modelled by using plane stress, shell or solid elements, which may be connected directly or via the hatch covers to the hull structure by either truss elements. The containers or the hatch covers have to be supported on the coaming by use of a vertically oriented truss element. At the location of the transverse and longitudinal stoppers the structure of the hatch covers will be supported either in transverse direction only or in transverse and longitudinal direction, respectively. The centre of gravity for the on-deck containers has to be correctly represented to get realistic heeling moments. If the containers in the holds are modelled by an auxiliary system, again special attention shall be paid to the vertical and horizontal force transfer to the appropriate nodes in the hull structure in order not to influence the stiffness of the ship.

1.4 Wave load analysis

The ship motions and the pressure distribution on the shell shall be calculated for different wave lengths, heights and heading angles. The design wave approach is based on the following assumptions:

— For every loading condition the hydrodynamic pressure and ship motions are calculated for different heading angles by a linear analysis. Application of the so-called strip theory is sufficient. In this approach pressure distribution is determined by linear analysis up to the still water line only.
— For different waves the hydrodynamic pressure is then adjusted to the real wave contour by a non-linear correction. The load magnitude including non-linear effects differs considerably from the linear response.

- Since the ship motions are based on the results of the linear analysis, the imbalances of forces due to the non-linear correction of pressures shall be compensated by adjustment of the ship accelerations. Inertia forces of the ship and hydrodynamic pressure shall be in equilibrium.
- In regular design wave approach, numerous wave situations are systematically analysed varying wave lengths, wave crest positions and headings. With these load cases the hull girder loads according to DNVGL-RU-SHIP Pt.3 Ch.4 Sec.4 [3.3], DNVGL-RU-SHIP Pt.3 Ch.4 Sec.4 [3.4] and DNVGL-RU-SHIP Pt.5 Ch.2 Sec.3 [2.2] shall be covered.
- Consideration of pressure and acceleration loads caused by free (resonant) rolling shall be included. The additional torsional moment due to inertia forces from the cargo during rolling may play an important part. The maximum rolling angle shall be determined on the basis of a refined ship motion analysis including rolling in a realistic way or on design values given in this document.
- For every loading condition around 20 load cases are finally selected for the finite element analysis. Selection of these load cases generally results in envelope curves of bending and torsional moment over the ship length, approximating the curves found in the systematic variation of wave situations and considering also other design load parameters such as acceleration and rolling.

The applied tools for calculation of wave loads shall be based on recognised software. All wave load programs that can show results to the satisfaction of the Society will be considered recognised software. The wave load analysis should be carried out for a ship's speed corresponding to 2/3 of the service speed. Additionally, non-linear effects shall be included in the wave load analysis.

1.5 Load cases for strength assessment

1.5.1 Design wave amplitude

The height of the design wave shall be chosen with respect to the vertical design bending moment given in DNVGL-RU-SHIP Pt.5 Ch.2 Sec.3 [2.2.3] and with a probability factor f_p as defined in DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8 Table 3.

As a first step, the most sensitive wave length for the vertical wave bending moment shall be found for the wave crest condition (hogging) and the wave trough condition (sagging). The most sensitive wave configuration (length and crest position) is defined as the condition where the vertical bending moment according to the rule is achieved with a wave height as small as possible. This wave configuration is the design wave.

For head and following seas a variation of the wave length from 0.8 to 1.2 L_W/L_{PP} shall be considered. During this variation process and during the systematic simulation in regular waves, the relevant wave amplitude A depends on the considered wave length.

$$\frac{A_i}{\sqrt[3]{\frac{L_{W,i}}{L_{pp}}}} = \frac{A_j}{\sqrt[3]{\frac{L_{W,j}}{L_{pp}}}} \qquad (1)$$

To compare the relevant amplitudes from different wave lengths, they shall be scaled on the wave length $L_W/L_{PP} = 1$.

For each wave length, a full period is considered. Therefore, 50 equidistant positions of the wave crest along the ship length are recommended.

The reference wave amplitude is the corresponding amplitude of the design wave scaled on the wave length $L_W/L_{PP} = 1$. The ratio of the reference wave amplitude for sagging and hogging condition corresponds to a correction factor for the sagging amplitude.

$$W_{cor} = \frac{A_{sagg}}{A_{hogg}} \qquad (2)$$

For positions of the wave crest between amidships (hogging condition) and the ship ends (sagging condition) following formula is used to adjust the wave amplitude A_{dyn}.

$$A_{dyn} = A_{\left(x/L_{pp} = 0.5\right)} \cdot \left(1 - \left(1 - W_{cor}\right)\right) \cdot \cos^2\left(\pi \cdot x/L_{pp}\right) \qquad (3)$$

For oblique and beam sea (30° – 150°) the sagging correction of the amplitude shall be neglected in case of W_{cor}>1.

1.5.2 Additional roll angle

Situations in oblique waves and by free rolling have been found to be decisive for several structural components.

Conventional wave load analysis cannot simulate the roll motion adequately. To solve this problem, the Society uses the method of additional roll angle to simulate realistic distribution of the torsional moment over the ship length.

In order to avoid severe load combinations, which are unlikely to occur, the additional roll angle shall be applied under the assumption that maximum wave amplitude A and extreme roll angle θ do not act simultaneously.

$$\sqrt{\left(\frac{A}{A_{(\theta = 0)}}\right)^2 + \left(\frac{\theta}{\theta_{\max}}\right)^2} = 1 \qquad (4)$$

This interaction formula assumes statistical independence between wave amplitude and additional roll angle.

Generally one combination of additional roll angle and wave amplitude shall be considered.

$$A = 0.25 \cdot A_{\max} \Rightarrow \theta = 0.97 \cdot \theta_{\max} \approx \theta_{\max} \qquad (5)$$

The maximum roll angle θ_{max} in degrees may be taken as:

$$\theta_{\max} = \frac{f_p \cdot 2500}{B + 60} \cdot f\left(GM_0\right) \qquad (6)$$

$f(GM_0)$	=	1.0 – exp ($-GM_{dyn}/GM_{min}$)
GM_{dyn}	=	$GM_0 + 0.01 \cdot B$
GM_{min}	=	$B^2/(8 \cdot L_{pp})$
GM_0	=	metacentric height of the actual loading condition
f_p	=	probability factor according to DNVGL-RU-SHIP Pt.6 Ch.1 Sec.8 Table 3

θ_{max} shall not be less than f_p*20 degree, reflecting the increased sensitivity in beam wind loads at low metacentric heights.

1.5.3 Variation of the wave parameters

In the regular design wave approach, a large number of waves is systematically analysed with different wave lengths, wave heading angles, additional roll angles and wave crest positions. Each additional roll angle, positive (starboard side immersed) and negative (port side immersed), is combined with 6 wave heading angles. The necessary wave length depends on the wave heading angle. Table 1 shows the relevant combinations of the wave parameters, which have be to analysed for each loading condition. Head and following seas correspond to 180 and 0 degrees respectively. Due to the symmetry of the ship geometry, it is sufficient to consider wave directions from one side. The heading angles 30, 60, 120 and 150 degrees correspond to waves from starboard.

Table 1 Variation of the wave parameters

additional roll angle θ	0°			$\pm\theta_{max}$		
wave Amplitude A	100%			25%		
wave heading angle Φ	0, 180	30, 150	60, 120	0, 180	30, 150	60, 120
$\frac{\text{wave length}}{\text{ship length}}$						
0.35			2 × 50			4 × 50
0.40			2 × 50			4 × 50
0.45			2 × 50			4 × 50
0.50		2 × 50	2 × 50		4 × 50	4 × 50
0.55		2 × 50	2 × 50		4 × 50	4 × 50
0.60		2 × 50	2 × 50		4 × 50	4 × 50
0.65		2 × 50	2 × 50		4 × 50	4 × 50
0.70		2 × 50			4 × 50	
0.80	2 × 50	2 × 50		4 × 50	4 × 50	
0.90	2 × 50	2 × 50		4 × 50	4 × 50	
1.00	2 × 50			4 × 50		
1.10	2 × 50			4 × 50		
1.20	2 × 50			4 × 50		
analysed wave situations	500	700	700	1000	1400	1400

For each combination of additional roll angle and heading angle a full wave period is considered. Also here 50 equidistant positions of the wave crest over the entire ship length are recommended. The resulting wave amplitude shall be based on the design wave amplitude and the corrections for wave length and wave crest position, as defined in [1.5.1]. Furthermore, for load cases with an additional roll angle, the relevant amplitude is reduced to 25% as defined in [1.5.2]. In total, 5700 situations of the vessel in regular waves shall be analysed.

1.5.4 Load case selection

The relevant load cases for FE analysis shall be selected by evaluating sectional forces and moments along the ship's length for all analysed wave situations. For these load combinations, vertical and horizontal wave bending and the torsional moments have to match design values defined in the rules.

Table 3 shows the moment's distribution of the dominant sea conditions. Table 2 shows the ratio of the maximum considered moments to the design values. For the torsional moments the zero-crossing point is also of primary importance. In upright conditions the torsional moment has a zero-crossing about at 0.5 x/L.

In conditions of free rolling (with additional roll angle $\theta_{\max}$) the point of zero-crossing depends on the loading condition. For the max SWBM it is positioned about at 0.3 x/L and for the min SWBM at 0.7 x/L. The applied bending and torsional moments shall approximately represent the envelope curves according to DNVGL-RU-SHIP Pt.3 Ch.4. Therefore it is necessary to select several load combinations of the dominant sea conditions.

Load case selection shall be done in a way to obtain the largest stress values.
For each loading pattern about 20 load combinations are finally selected for the finite element analysis.
A detailed description of the load case selection process is given in /1/.

Table 2 Moment factors

	Still water static moments		*Wave-induced dynamic moments*		
	Vertical	*Torsion*	*Vertical*	*Horizontal*	*Torsion*
Head and follow sea	1	1	f_p	0	0
Oblique sea	1	1	$0.7{*}f_p$	f_p	f_p
Free rolling	1	1	$0.35{*}f_p$	f_p	f_p

Table 3 Load case selection

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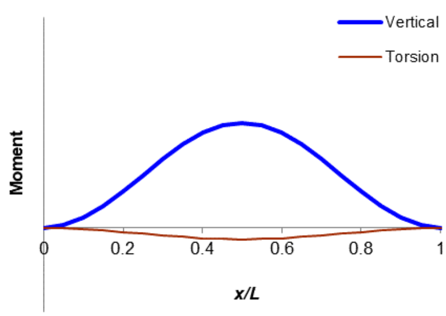
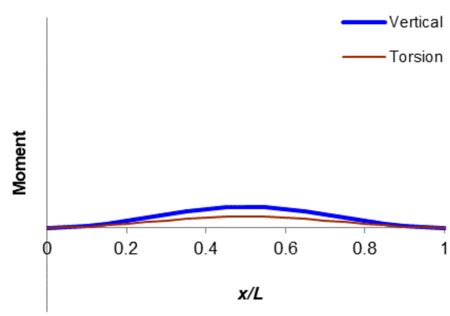
<tr><td>Stillwater</td><td>
</td><td>
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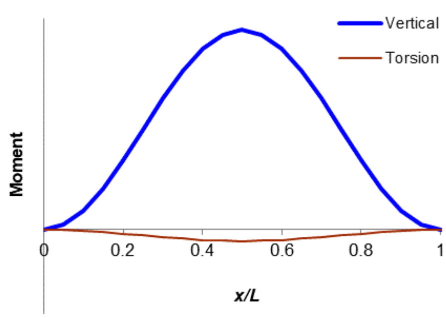
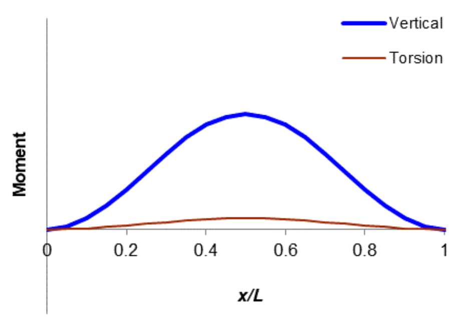
<tr><td>Max hogging</td><td>
</td><td>
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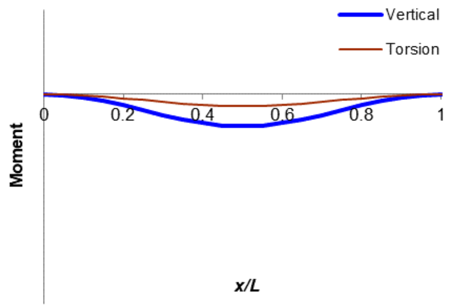
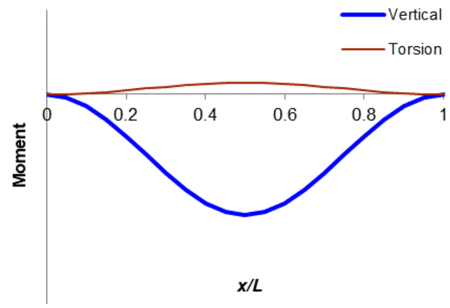
<tr><td>Max sagging</td><td>
</td><td>
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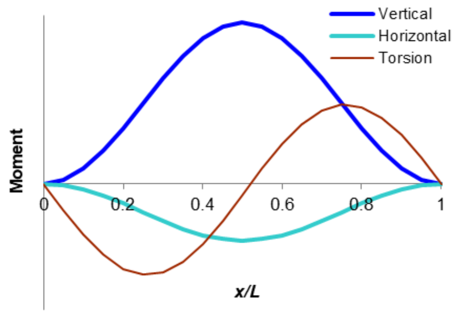
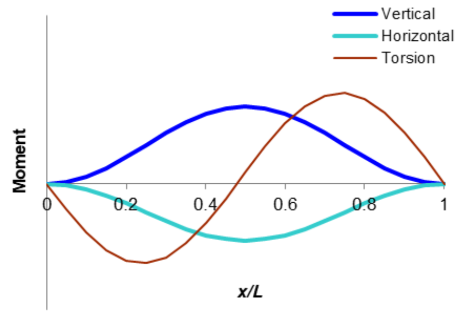
<tr><td>Oblique sea in wave crest</td><td>
</td><td>
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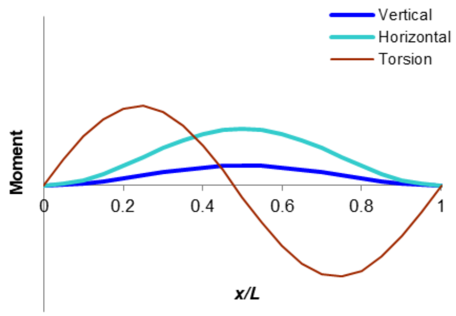
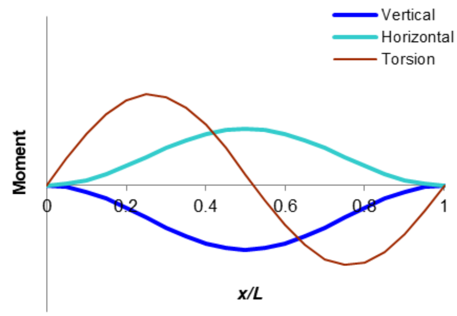
<tr><td>Oblique sea in wave trough</td><td>
</td><td>
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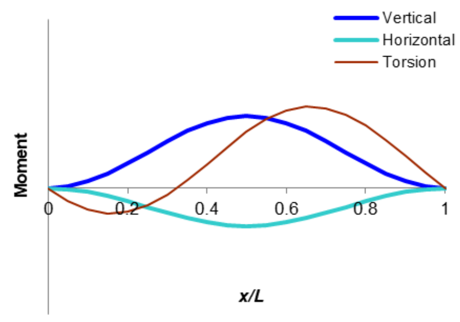
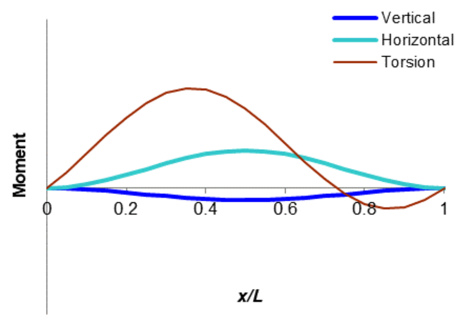
<table>
<tr><th></th><th>Max stillwater bending moment</th><th>Min stillwater bending moment</th></tr>
<tr><td>Free rolling, StB submerged</td><td>
</td><td>
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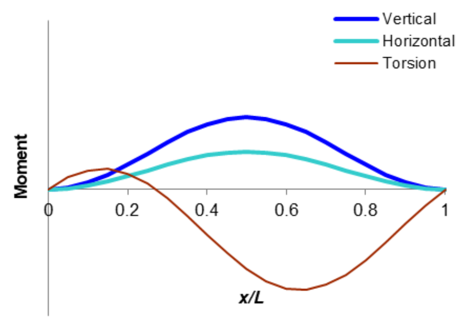
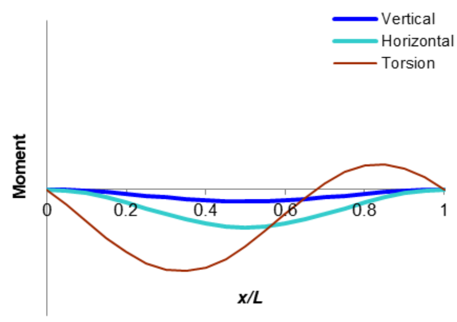
<tr><td>Free rolling, PS submerged</td><td>
</td><td>
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1.5.5 Loads on bow and stern structures

Consideration of slamming loads is crucial for ships with excessive bow flare and stern overhang. Since direct calculation of slamming loads is extensive and time consuming, a simplified method based on rule defined impact pressures is recommended for global strength analysis. The concept used to obtain balanced load cases comprises the following steps:

— Consideration of static weight loads and stillwater pressures. No hydrostatic loads are applied to elements where impact pressures are at least as large as the static pressure.
— Dynamic pressures on shell elements are computed from DNVGL-RU-SHIP Pt.3 Ch.10 Sec.1 and DNVGL-RU-SHIP Pt.3 Ch.10 Sec.3 for bow area and stern areas, respectively.
— Mean impact pressures of 0.375 P_{FB} on bow or mean slamming pressure of 0.375 P_{SS} on stern areas are applied in a way that, in combination with dynamic weight loads, the resulting vertical wave bending moment does not exceed the rule wave sagging bending moment. This restriction is required between 10% and 90% of the ship's length. For typical vertical bending moment distributions, see Figure 3.
— For this purpose, bow and stern areas with at least 10° flare angle are divided into several vertical areas parallel to waterline. Load cases are generated by adding slamming loads, area by area, until the required vertical bending moment is reached. If necessary, the impact pressure on the last added area is scaled by a factor less than one, so that the resulting vertical bending moment does not exceed the rule bending moment.
— In this way, several load cases are generated until at each z-position above the ballast waterline the mean bow impact or mean stern slamming pressure is applied.

Each slamming load case results from the combination of impact pressure, hydrostatic pressure, and weight loads. These loads are balanced by adjusting the dynamic acceleration factors for the weight loads. This procedure represents the slamming condition for global strength analyses in a simple but realistic way and enables dimensioning of fore and aft ship areas.

The evaluation is limited to permissible stresses and buckling strength only. The fatigue criteria are ignored for slamming load cases.

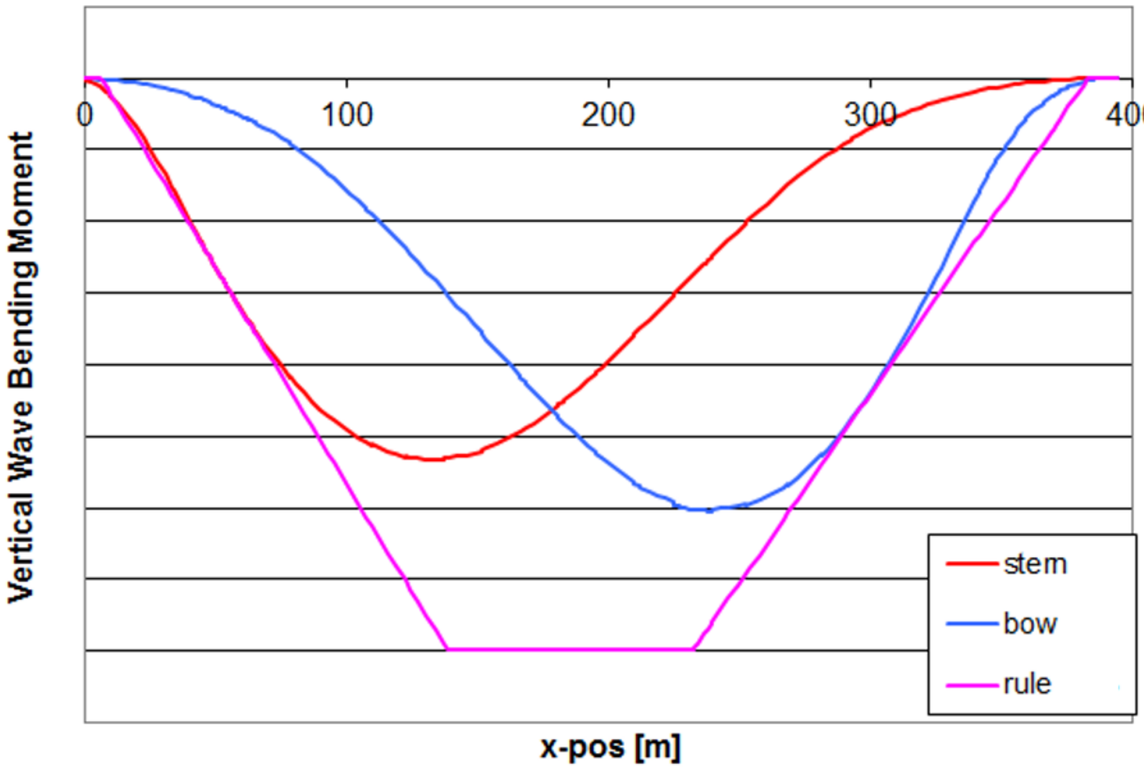

Figure 3 Vertical wave bending moments for slamming load cases

1.6 Load cases for fatigue assessment

Equivalent design waves (EDW) for fatigue load cases as defined in DNVGL-RU-SHIP Pt.3 Ch.4 Sec.2 [3] shall be selected from a set of systematic varied load cases. Each EDW shall maximise or minimise a dominant load component at a given location.

Due to the symmetry of the ship geometry, it is sufficient to consider wave directions from one side. The heading angles 60 and 90 degrees correspond to waves from starboard.

For the relevant heading angle of the considered EDW and the use of a unit wave amplitude of 1.5 m, wave conditions with different lengths and crest positions are analysed to find the condition with highest response on the dominant load component. In a second step the wave amplitude shall be adjusted in a linear way, until the dominant load component reached the rule value at relevant location. For the rule value the coefficient f_p shall be taken as defined in DNVGL-RU-SHIP Pt.3 Ch.4 for fatigue assessment.

Contrary to load case selection forstrength assessment, here for fatigue strength the relevant wave amplitude is determined for each EDW individually and no corrections in dependence of the wave length and wave crest location are applied. Furthermore no additional roll angle is applied, roll motions are represented by conditions in the natural roll period only.

1.6.1 Head and following sea (HSM & FSM)

For one set of conditions with head (HSM) and following (FSM) seas a variation of the wave length from 0.8 to 1.2 L_W/L_{pp} shall be carried out with a step size of 0.05 L_W/L_{pp}. For each wave length a scan at least over 50 equidistant wave crest positions is necessary to find the condition with the highest response on the vertical bending moment at midship in hogging and sagging wave. For the most sensitive hogging condition either in head or following sea the amplitude shall be adjusted, until at the location with maximum vertical bending moment the rule value is fulfilled. Same amplitude shall be used for the less sensitive heading angle in hogging condition, so that the amplitude for the EDWs HSM2 and FSM2 is identical.

In the same way a separate adjustment of the wave amplitude in the sagging condition shall be carried out to fulfill the minimum vertical bending moment. This amplitude shall be applied for the EDWs HSM1 and FSM1.

1.6.2 Oblique sea (OST)

For conditions in oblique sea (OST-S) a variation of the wave length from 0.35 to 0.65 L_W/L_{pp} shall be carried out for a heading angle of 60°. For each wave length a scan at least over 50 equidistant wave crest positions is necessary to find the condition with the highest response on the torsion moment in way of x/L = 0.25 - 0.35 in hogging (OST-2S) and sagging (OST-1S) wave. For the most sensitive condition of OST-1S the amplitude shall be adjusted, until at the location with maximum torsion moment the rule value is fulfilled. Same amplitude shall be used for further wave crest positions to reflect the torsional envelope curve in way of x/L = 0.20 - 0.45 at least by three load cases. In the same way a separate adjustment of the wave amplitude for OST-2S shall be carried out, to represent the minimum envelope curve of torsion moment.

1.6.3 Beam sea roll (BSR)

For conditions in beam sea with large roll angles (BSR-S) in a heading angle of 90° such wave lengths shall be scanned, where it is expected that the wave period match with the roll period. At least 50 equidistant wave crest positions shall be checked for each wave length, to find the condition with the highest response on the torsion moment in way of x/L = 0.65 - 0.75 due rolling to starboard (BSR-1S) and to portside (BSR-2S). For the most sensitive condition of BSR-1S the amplitude shall be adjusted, until at the location with maximum torsion moment the rule value is fulfilled. Same amplitude shall be used for conditions where the ship rolls to portside in BSR-2S and the resulting torsion moment reach his minimum value.

On basis of the roll period according to DNVGL-RU-SHIP Pt.3 Ch.4 Sec.3 [2.1.1] and the wave period with :

$$T_{wave} = \sqrt{\frac{2\pi \cdot L_W}{g}} \qquad (7)$$

the critical wave lengths L_W in [m] can be expected between $6.5\, k_r^{\,2}/GM$ and $9.0\, k_r^{\,2}/GM$.

1.6.4 Beam sea pressure (BSP)

For conditions in beam sea with high pressure on starboard side (BSP-S) a variation of the wave length from 0.25 to 0.55 L_W/L_{pp} shall be carried out for a heading angle of 90°. For each wave length a scan at least over 50 equidistant wave crest positions is necessary to find the condition with the highest hydrodynamic pressure amidships on starboard side 5 m below waterline. For the most sensitive condition of BSP-1S the amplitude shall be adjusted, until the rule value is fulfilled. In the same way a separate adjustment of the wave amplitude for BSP-2S shall be carried out, to find the condition with minimum pressure on starboard side.

2 Fatigue assessment

The global finite element analysis allows for the consideration of fatigue aspects. The fatigue strength assessment is to be carried out as described in DNVGL-CG-0129 *Fatigue assessment of ship structures*.

2.1 Fatigue stress range and mean stress

For each loading condition the maximum and minimum stress has to be determined. Port side and starboard side are to be combined to determine the maximum stress range, because wave directions are considered from only one side in the load case selection. In general, the mean stress is to be taken as the arithmetic mean of the maximum and minimum stress that yield the maximum stress range.

The fatigue stress range including correction factors, e.g. for mean stress, is to be determined according to DNVGL-CG-0129 Sec.3 [2].

2.2 Fatigue assessment of hatch corners

2.2.1 Local model

Fatigue assessment of hatch corners is to be carried out by fine mesh analysis by means of a local model. This model shall extend at least one web space aft and forward of the considered hatch corner in the longitudinal direction, and one container height above and below. Secondary stiffeners may be represented by truss elements as in the global model. Alternatively, hatch corners may be modelled with a fine mesh directly in the global finite element model.

A maximum stress range is to be derived within each loading condition. The results are sensitive to the mesh arrangement in way of the hatch corner area. Therefore, it is required that an arc equal to a quarter of a circle is divided into at least 10 elements. To evaluate the edge stresses of the hatch corner it is sufficient to arrange truss elements along the free edge with a zero cross sectional area.

2.2.2 Load application

The deflections obtained from the global analysis will be applied to the relevant nodes of the local model as forced deformations. If the size of the local model is greater than in the description above, local loads like container loads and sea pressures shall be applied on the local model if relevant.

2.3 Fatigue assessment of longitudinal stiffener end connections

For the fatigue assessment of end connections of longitudinal stiffeners in the side shell and bilge, the global longitudinal hull girder stress, the local external pressures, and the relative deflections of supporting transverses can be evaluated by the global strength analysis.

The longitudinal hot-spot stress due to hull girder wave loads is to be taken for each load case equal to the nominal uniaxial dynamic hull girder stress from the global strength analysis, multiplied by the hot-spot stress concentration factor K_a according to DNVGL-CG-0129 App.A. Similarly, the hot-spot stress due to still water hull girder bending moment is to be taken equal to the nominal uniaxial static hull girder stress from the global strength analysis, multiplied by the hot-spot stress concentration factor K_a according to DNVGL-CG-0129 App.A.

The hot-spot stress due to stiffener bending from dynamic pressure shall be calculated according to DNVGL-CG-0129 Sec.4 [6.1]. The dynamic wave pressure P_W for each load case is to be taken equal to the external dynamic pressure from the wave load analysis and the factor f_{NL} is to be taken equal to 1.0. The dynamic liquid tank pressure, P_{ld}, is to be taken equal to zero. The hot-spot stress due to stiffener bending from static pressure shall be calculated according to DNVGL-CG-0129 Sec.4 [6.2]. The static wave pressure P_S is to be taken equal to the external static pressure from the global strength analysis. The static liquid tank pressure, P_{ls}, is to be taken equal to the prescriptive static tank pressure.

The hot-spot stress due to dynamic relative displacement shall be calculated for each load case according to DNVGL-CG-0129 Sec.4 [7.5] based on dynamic relative displacement taken from the global strength analysis. Similarly, the hot-spot stress due to static relative displacement shall be calculated according to DNVGL-CG-0129 Sec.4 [7.6] based on static relative displacement taken from the global strength analysis.

Stresses due to double hull bending are already included in the global longitudinal hull girder stress taken from the global strength analysis.

2.4 Fatigue assessment of other welded details

For the fatigue assessment of welded details, e.g., transverse butt welds, hatch cover resting pads, equipment holders etc. in the upper part of the hull girder the evaluation of permissible stress concentration factors or required FAT classes according to DNVGL-CG-0129 Sec.3 [5], based on nominal stress from the global FE analysis, may be convenient. Also for the fatigue assessment of flange intersections of stringers and vertical girders of transverse bulkheads this method may be chosen.

Knuckles and discontinuities of longitudinal structural members in the upper part of the hull girder shall be assessed using local models as described in DNVGL-CG-0129 Sec.6. Alternatively, these details may be modelled with a fine mesh directly in the global finite element model.

3 Hatch cover movements

One important result of the global strength analysis is the determination of the deformed hatch diagonal dimension and the determination of the hatch cover movements relative to the hatch coaming and relative to the adjacent hatch covers. In Figure 4 the different positions are shown.

The evaluation values depend on the deformation of the coaming and on the stopper positions. Any clearances in the stopper are neglected in the evaluation. These values shall be added to the calculated values accordingly.

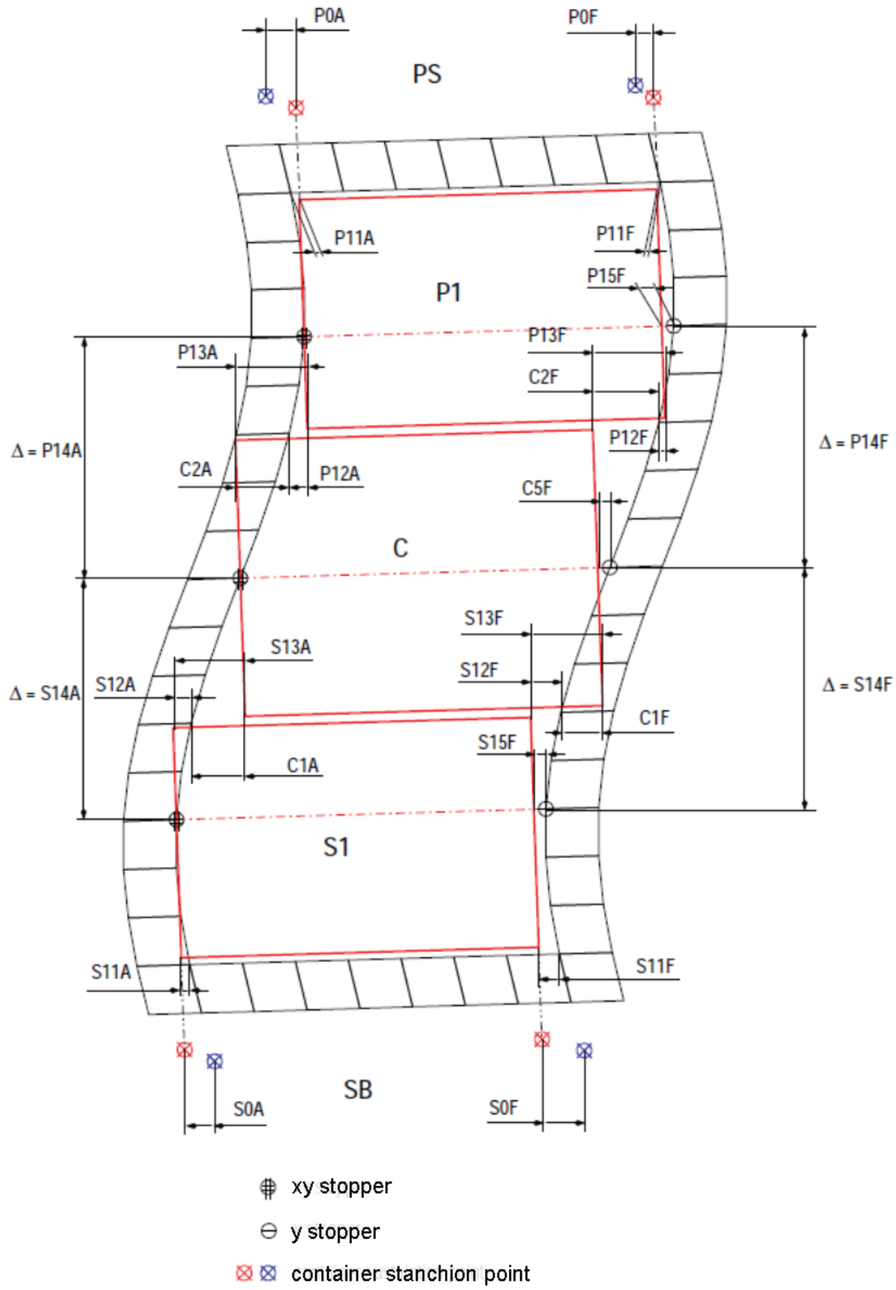

Figure 4 Hatch cover movements

4 Embedded cargo hold analysis

4.1 General

The cargo hold FEA according to DNVGL-RU-SHIP Pt.5 Ch.2 Sec.6 can be carried out with the global FE-model, when the mesh size in mid ship area corresponds with the stiffener spacing as described in DNVGL-CG-0127 Sec.3 [2.2.4] .

4.2 Direct wave load analysis

Based on the load procedure described in [1] the required load combinations according to DNVGL-RU-SHIP Pt.5 Ch.2 Sec.6 Table 1 and DNVGL-RU-SHIP Pt.5 Ch.2 Sec.6 Table 2 are to be generated by direct wave load analysis for a 10^{-8} probability level of exceedance. Inside the investigated cargo hold and the two adjacent holds the loading patterns shall be in alignment with the required ones of Table 1 or Table 2. Outside of these three holds the loading patterns can be adjusted in such a way, that the required draught and still water bending moment can be fulfilled on an even trim. To achieve the deepest equilibrium waterline T_{DAM} for LC7 “Flooded damaged condition”, all compartments shall be filled in the global FE-model as described for the selected damaged scenario.

4.3 Yield acceptance criteria

Verification against the yield criteria shall be carried out according to DNVGL-RU-SHIP Pt.3 Ch.7 Sec.3 [4.2].

4.4 Buckling acceptance

Verification against the buckling criteria shall be carried out according to DNVGL-RU-SHIP Pt.3 Ch.8 Sec.4.

5 References

/1/ Eisen, H., Rörup, J., Scharrer, M. (2009); *Automatic Selection of CFD-based Design Loads for the FEM Analysis of Ship Structures* 10th International Marine Design Conference, Trondheim.

CHANGES – HISTORIC

January 2018 edition

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

Topic	*Reference*	*Description*
Calibration of rule calculated fatigue life	Sec.2 [1.5] and Sec.2 [1.6]	Different procedures of load case generation for ULS and FLS has been defined. Fine tuning of the two procedures based on analysis of four container ships has been carried out. These modifications are necessary for application of DNV GL-rules and introduction of the IACS requirements in UR S11A.

October 2015 edition

This is a new document.

Amendments February 2016

• General

— Only editorial corrections have been made.