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GUIDANCE NOTE FOR STRUCTURAL ASSESSMENT OF PASSENGER SHIPS AND RO-RO SHIPS

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GUIDANCE NOTE

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These rules are provided within the scope of the Bureau Veritas Marine & Offshore General Conditions, enclosed at the end of Part A of NR467, Rules for the Classification of Steel Ships. The current version of these General Conditions is available at the Bureau Veritas Marine & Offshore website.

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Section 1 General

1 General

1.1 Introduction

1.1.1 The aim of this Guidance Note is to detail specific hull related items to be considered during the structural assessment of passenger ships, ro-ro passenger ships and ro-ro cargo ships as well as procedures for specific structural calculations.

This Guidance Note may be used as a complement to NR467 Rules for the Classification of Steel Ships.

In the present Note, the term “passenger ship” refers to ships granted with the service notation **passenger ship** as defined in NR467, Pt A, Ch 1, Sec 2. The term “ro-ro passenger ship” refers to ships granted with the service notation **ro-ro passenger ship** as defined in NR467, Pt A, Ch 1, Sec 2. The term “ro-ro cargo ship” refers to ships granted with the service notation **ro-ro cargo ship** as defined in NR467, Pt A, Ch 1, Sec 2.

1.2 Reference documents

1.2.1 The main rules and documents referenced in this Guidance Note are listed below:

- NR467 Rules for the Classification of Steel Ships
- IMO SOLAS Convention 1974, as amended
- IMO International Convention on Load Line 1966, as amended, referred to as ICLL
- IMO LSA Code 1996, as amended
- NI429 Guidelines for the Preparation of the Cargo Securing Manual
- IACS Unified Requirements, as amended, referred to as UR.

2 Information to be submitted

2.1 General

2.1.1 The documents to be submitted for review and/or information are listed in NR467, Pt B, Ch 1, Sec 4, Tab 1.

2.1.2 Additional specific information to be submitted for passenger ships, ro-ro passenger ships and ro-ro cargo ships review are given in NR467, Pt D, Ch 11, Sec 3, [1.1], NR467, Pt D, Ch 12, Sec 3, [1.1] and NR467, Pt D, Ch 1, Sec 2, [1.2] respectively.

2.1.3 A detailed report of the structural analysis is to be submitted by the designer/builder to demonstrate compliance with the specified structural design criteria. This report is to include the following information:

a) list of plans used including dates and versions

b) detailed description of structural modeling including all modeling assumptions and any deviations in geometry and arrangement of structure compared with plans

c) plots to demonstrate correct structural modeling and assigned properties

d) details of material properties, plate thickness, beam properties used in the model

e) details of boundary conditions

f) details of all loading conditions reviewed with calculated hull girder shear force, bending moment and torsional moment distributions

g) details of applied loads and confirmation that individual and total applied loads are correct

h) plots and results that demonstrate the correct behaviour of the structural model under the applied loads

i) summaries and plots of global and local deflections

j) summaries and sufficient plots of stresses to demonstrate that the design criteria are not exceeded in any member

k) plate and stiffened panel buckling analysis and results

l) tabulated results showing compliance, or otherwise, with the design criteria

m) proposed amendments to structure where necessary, including revised assessment of stresses, buckling and fatigue properties showing compliance with design criteria

n) reference of the finite element computer program, including its version and date.

Alternatively, and on a case by case basis, the analysis model might be submitted in lieu of the documents listed above.

3 Sensitive items

3.1 General

3.1.1 As a summary, specific attention is to be paid to the following sensitive items:

- openings in decks/bulkheads/superstructure side shell
- supporting structure in way of life saving appliances
- pillars
- structures subject to wheel loads
- buckling of thin plates for upper decks
- ro-ro equipment and connections to the structure
- aluminium structures
- watertight integrity of ro-ro spaces.

4 Cargo securing manual

4.1 General

4.1.1 In accordance with SOLAS Chapter VI, Part A, Reg 5 and Chapter VII, Part A, Regulation 5, cargo units and cargo transport units are to be loaded, stowed and secured through the voyage in accordance with the cargo securing manual.

The manual is to be drawn up to a standard at least equivalent to the guidelines developed by IMO and is to be approved by the Society.

All items which are to be covered by the manual are described in NI429 Guidelines for the preparation of the cargo securing manual.

Specific attention is to be given to the following items:

- distance between the lashing points (longitudinal and transverse) is to be defined
- certificates of all cargo securing devices (fixed and portable) are to be included in the manual
- text copied from cargo securing manual models but not applicable to the concerned ship is to be removed.

Section 2 Ship Arrangement

1 General

1.1 Application

1.1.1 The requirements of Article [2] apply to both passenger ships and ro-ro passenger ships.

The requirements of Article [3] apply to ro-ro passenger ships only.

1.2 International regulations

1.2.1 The different requirements listed in this Section are mostly directly issued from SOLAS and Load Line conventions.

It is important to keep in mind that almost all these requirements deal with important design features of the ship. These points are therefore to be clarified at the very beginning of the project, as they may impact directly the general arrangement of the ship.

1.3 Definitions

1.3.1 Bulkhead deck and freeboard deck

The term bulkhead deck is defined in:

- NR467, Pt B, Ch 1, Sec 3, [2.6.3] and
- refers to SOLAS II-1Reg 2 -19.

The term freeboard deck is defined in:

- NR467, Pt B, Ch 1, Sec 3, [2.6.5] and
- ICLL Annex 1 Ch 1 Reg 3 (9).

On passenger ships and ro-ro passenger ships, the bulkhead deck and the freeboard deck are usually the same deck.

1.4 Main structural items

1.4.1 On the general arrangement drawing, specific attention is to be given to the:

- double bottom height and extent
- number and arrangement of transverse watertight bulkheads
- location and arrangement of the collision bulkhead
- location and arrangement of after peak bulkhead and machinery space bulkhead
- arrangement of tanks
- watertight integrity of ro-ro spaces
- location of shell openings.

2 Arrangement of passenger ships and ro-ro passenger ships

2.1 After peak bulkhead and stern tubes

2.1.1 After peak bulkhead and stern tubes are to be checked according to NR467, Pt B, Ch 2, Sec 1, [4].

2.2 Watertight doors

2.2.1 Watertight doors are to be checked according to:

- NR467, Pt B, Ch 4, Sec 5, [10.7]
- NR467, Pt B, Ch 11, Sec 8
- NR467, Pt D, Ch 11, Sec 2, [2.3] or
- NR467, Pt D, Ch 12, Sec 2, [2.3], as relevant.

2.2.2 The review of watertight doors is in most cases a separate review for the supplier of the doors. The maximum water column supported by the door is to be indicated on the drawings. This value is to be at least equal to the rule value of pressure applied to the door. Therefore, it is necessary to clarify the exact location of each door on the ship.

2.2.3 Requirements regarding watertight doors above the freeboard decks in ro-ro passenger ships are detailed in [3.8].

2.3 Doors and hatch coamings sills

2.3.1 Positions 1 and 2 for passengers ships and ro-ro passenger ships

Attention is to be paid to the specific definitions of positions 1 and 2 for passenger ships and ro-ro passenger ships (see NR467, Pt B, Ch 1, Sec 3, [2.4]).

2.3.2 Door sills

Door sills are to be checked in accordance with:

- NR467, Pt B, Ch 11, Sec 12, [7.2]
- NR467, Pt B, Ch 11, Sec 12, [8.3]
- NR467, Pt B, Ch 11, Sec 7, [1.3.2]
- ICLL Regulation 24.

Reduced sill height may be accepted on a case by case basis above the lowest position 2 deck.

2.3.3 Hatch coaming sills

Hatch coaming sills are to be checked in accordance with NR467, Pt B, Ch 11, Sec 10, [2.1].

2.4 Openings in the side shell

2.4.1 Location and arrangement

Requirements regarding location and arrangement of openings in the side shell are given in:

- NR467, Pt B, Ch 11, Sec 7
- NR467, Pt B, Ch 11, Sec 12
- NR467, Pt B, Ch 11, Sec 8.

2.4.2 Windows and side scuttles

Requirements for windows and side scuttles are listed in NR467, Pt B, Ch 11, Sec 12, [3].

Requirements for deadlights of side scuttle and windows are described in NR467, Pt B, Ch 11, Sec 12, [3.4].

Windows glass is to be checked in accordance with NR467, Pt B, Ch 11, Sec 12, [3.3]. The design pressure for glass is to be calculated in accordance with NR467, Pt B, Ch 5, Sec 5, [5] at the center of the glass pane.

In all cases the minimum flexural strength [N/mm^2] of the glass panes is to be submitted by the designer and specified in the drawings. If no information has been received the minimum rule values given in NR467, Pt B, Ch 11, Sec 12 may be used. The values considered are to be indicated on the drawings.

2.5 Watertight trunks and ventilation ducts

2.5.1 Watertight trunks and ventilation ducts are to be checked according to NR467, Pt B, Ch 4, Sec 5, [10.5.1].

2.6 Freeing ports

2.6.1 General

Where bulwarks form wells on weather portions of freeboard or superstructure decks, provision shall be made for rapidly freeing the decks of water and for draining them. The requirements are given in ICLL Regulation 24 and are also described in NR467, Pt B, Ch 11, Sec 12, [6].

2.7 Fender arrangement in way of life saving appliances

2.7.1 Attention is to be paid to the arrangement and construction of fenders in way of life saving appliances.

According to the LSA Code, survival crafts and rescue boats are to be able to be launched under unfavorable conditions of trim up to 10° and list up to 20° either way. The design and shape of the fenders are to be such that the launching of the survival craft is possible in those conditions without causing the survival craft to be stuck on the fender.

Fenders as well as windows and sidescuttles in the above mentioned sector in way of marine evacuation system (MES) should be designed so as to avoid any coarse surface in order to prevent injury during embarkation.

2.8 Guard rails

2.8.1 Requirements regarding fitting and design of guard rails are given in NR467, Pt B, Ch 12, Sec 2 (based on ICLL Regulation 25).

2.8.2 Attention is to be paid to possible specific requirements from flag authorities regarding the design of guard rails in way of public deck areas, where horizontal bars may have to be replaced by vertical bars in order to prevent climbing onto the guard rails.

2.9 Anchor and mooring equipment

2.9.1 Equipment number

The equipment number for passenger ships and ro-ro passenger ships is to be calculated in accordance with NR467, Pt B, Ch 12, Sec 4. Mooring and anchoring equipment are to be chosen in the corresponding tables.

In addition, small vessels like double end ferries are to be specifically considered with respect to the calculation of the equipment number. The open area below the deckhouse may be disregarded when defining "h" for the calculation. The ramp is to be treated as a bulwark, which is to be included in case h is greater or equal than 1,50 m.

2.10 Tank arrangement

2.10.1 Fresh water tanks

It should be noted that some flag authorities do not accept the arrangement of fresh water tanks adjacent to water ballast tanks due to possible health risks in case of leakage through welding seams.

3 Specific requirements for ro-ro passengers ships

3.1 General

3.1.1 Ro-ro passenger ships are equipped with several specific pieces of equipment in order to load and store vehicles onboard.

These are typically:

- bow door
- bow ramp
- stern door/ramp
- movable decks
- inner ramps
- external ramps
- ramp covers.

3.1.2 Structural reinforcements in way of these pieces of equipment are to be designed taking into account the reaction forces submitted by the supplier.

In case no values have been transmitted, the maximum forces found during the review of the equipment are to be considered.

3.1.3 The allowable stresses to be considered for the review of connections of ro-ro equipment to the hull structure are given in NR467, Pt B, Ch 7, Sec 6, [5].

3.2 Bow door

3.2.1 A ro-ro passenger ship is generally equipped with a bow door and bow ramp (see also [3.3.2]) in combination with the stern ramp (see [3.4]) in order to enable the continuous loading and unloading without the need of turning around inside the ship.

Two different kinds of bow doors can be identified:

- visor door
- side opening doors.

3.2.2 Requirements regarding bow door structure are based on IACS UR S8 and are detailed in NR467, Pt B, Ch 11, Sec 6.

Attention is to be paid to the fact that rule scantlings are given as gross scantlings.

3.2.3 Securing and supporting devices

Special attention is to be paid to specific requirements regarding securing and supporting devices, including redundancy, given in:

- NR467, Pt B, Ch 11, Sec 6, [5.1.2]
- NR467, Pt B, Ch 11, Sec 6, [5.2.6]
- NR467, Pt B, Ch 11, Sec 6, [5.2.7].

3.3 Inner door

3.3.1 General

In case a bow door is provided, an inner door is to be fitted aftwards and is generally also used as forward loading ramp. Special attention is to be paid to the arrangement of this inner door.

Requirements regarding the inner door structure are based on IACS UR S8 and are detailed in NR467, Pt B, Ch 11, Sec 6.

Attention is to be paid to the fact that rule scantlings are given as gross scantlings.

3.3.2 Inner door acting as forward ramp

In case the inner door is also acting as a forward ramp, the structure is to be checked in accordance with the requirements of NR467, Pt B, Ch 2, Sec 1, [3.1.6] and NR467, Pt B, Ch 11, Sec 11 (see also [3.5]).

3.3.3 Scantling of hinges

Scantlings of hinges are to be checked according to:

- NR467, Pt B, Ch 11, Sec 6, [2]
- NR467, Pt B, Ch 11, Sec 6, [5]
- NR467, Pt B, Ch 11, Sec 6, [6].

The scantlings of hinges are to be checked with respect to the following items:

- surface pressure in the hinge plate and hinge brackets due to the contact area with the hinge axle
- bending stress in the hinge axle
- shear stress in the hinge axle
- shear stresses in the hinge blade and brackets.

3.4 Side/stern door and ramp

3.4.1 General

Requirements regarding stern door structure are based on IACS UR S9 and are detailed in NR467, Pt B, Ch 11, Sec 7.

Attention is to be paid to the fact that rule scantlings are given as gross scantlings.

3.4.2 Opening direction

As mentioned in NR467, Pt B, Ch 11, Sec 7, [1.3.3], doors are preferably to open outwards.

However, doors located on the side shell above the freeboard deck may open inwards subject to the approval of the Society.

3.4.3 Stern door acting as stern ramp

In case the stern door is acting also as stern ramp, the structure is to be checked in compliance with NR467, Pt B, Ch 11, Sec 11, [2]. (see also [3.5])

3.4.4 Securing and supporting devices

Special attention is to be paid to specific requirements regarding securing and supporting devices including redundancy given in NR467, Pt B, Ch 11, Sec 7, [4.1.2] and NR467, Pt B, Ch 11, Sec 7, [4.2.3].

3.5 Movable decks and inner ramps

3.5.1 General

Movable decks and inner ramps are covered by NR467, Pt B, Ch 11, Sec 11, [1].

3.5.2 Scantlings

Scantlings of inner ramps and movable decks are also to be in compliance with Sec 3, [4], Sec 3, [5], Sec 3, [6].

The loading cases which are to be considered for the verification of the primary structure are described in NR467, Pt B, Ch 11, Sec 11, [1.5].

Requirements for supports, suspensions and locking devices are given in Pt.B, Ch.11, Sec.11, [1.6].

3.5.3 Allowable deflection

Special attention is to be paid to the allowable deflection defined in NR467, Pt B, Ch 11, Sec 11, [1.5.5] to be complied with in addition to strength requirements.

3.6 External ramps

3.6.1 General

External ramps are covered by NR467, Pt B, Ch 11, Sec 11, [2].

3.6.2 Scantlings

Scantlings of external ramps are to be in compliance with Sec 3, [4], Sec 3, [5], Sec 3, [6].

Maximum heel and trim angles for which the ramp is to be able to operate in harbour condition are defined in NR467, Pt B, Ch 11, Sec 11, Tab 1.

For this purpose a 3D model should be created which will be loaded in accordance with the specific wheel loads. Where the ramp is connected to the ship, forced displacements are to be applied to the ramp nodes, corresponding to the displacements induced by the maximum heel and trim angle of the ship.

3.7 Ramp covers

3.7.1 General

Two different types of ramp covers may be used:

- side hinged covers
- end hinged covers (crocodile types).

3.7.2 Scantling of ramp covers

In case a ramp cover is also used as a ramp, requirements given in NR467, Pt B, Ch 11, Sec 11, [1] are also to be checked (see also [3.5]).

Watertight ramp covers are also to be checked regarding flooding pressure defined in Sec 3, [2.4.1] considering scantling criteria given in NR467, Part B, Chapter 7.

In addition to the structural review of the cover itself, attention is to be paid to the following items:

- transition area of the ramp (change of inclination angle)
- deck openings (corner radius).

3.8 Watertight doors above the freeboard deck

3.8.1 Stockholm agreement (1996)

The Stockholm agreement (IMO circular letter 1891) describes requirements regarding the stability of ro-ro passenger ships and the possible required transverse watertight doors on the freeboard deck of ro-ro passenger ships.

This agreement applies to all ro-ro passenger ships with EU-flag and/or which are operating in EU-harbors.

3.8.2 Watertight doors in ro-ro spaces above the freeboard deck

Watertight doors in ro-ro spaces above the freeboard deck are to be checked according to NR467, Pt D, Ch 12, Sec 2, [2.4.5].

Both the height of these doors and the hydrostatic pressure to be applied for their scantlings evaluation (as calculated according to NR467, Pt B, Ch 5, Sec 6, [1.4]) depend on the results of the damage stability calculation.

3.9 Watertight integrity of ro-ro decks

3.9.1 Requirements regarding watertight integrity of ro-ro decks are given in NR467, Pt D, Ch 12, Sec 2, [2.4.2] and NR467, Pt D, Ch 12, Sec 2, [2.4.3].

3.10 Fixed cargo securing equipment/lashing points

3.10.1 Two different kinds of lashing points can be distinguished:

- lashing points fitted below the deck
- lashing points fitted above the deck.

In both cases, the integration of these points into the deck structure is to be carefully checked. Special attention is to be paid to the following points:

- absence of hot spots in the deck plating
- proper welding of the lashing points to the deck
- proper support of the lashing point
- validity of certificates for the lashing equipment.

In addition, it is to be checked if additional special requirements regarding cargo securing equipment are given by the flag authorities.

3.11 Helicopter landing and pick-up area

3.11.1 Specific requirements regarding helicopter landing and pick-up areas in ro-ro passenger ships are defined in SOLAS Chapter III, Part B, Reg 28:

- all ro-ro passenger ships shall be provided with a helicopter pick-up area (...). (paragraph 21)
- ro-ro passenger ships of 130m in length and upwards (...) shall be fitted with a helicopter landing area (...). (paragraph 2).

3.11.2 The structural requirements for these areas are given in Pt B, Ch 11, Sec 13.

3.12 Superstructure side shell transition

3.12.1 In general, on ro-ro passenger ships, the transition of the superstructure side shell aft and fore of the deckhouse is a critical area, which is to be carefully checked in order to avoid cracks due to high stress concentration. The reason of these stress concentrations is the rapid decrease of section modulus and shear area of the transverse cross sections.

Section 3 Hull Scantling

1 General

1.1 Corrosion addition

1.1.1 The corrosion additions to be considered are defined in NR467, Pt B, Ch 4, Sec 3.

1.1.2 The net thickness of plating which constitutes primary supporting members analysed through a three dimensional model or complete ship model is to be obtained by deducting half of the corrosion addition from the gross thickness, according to NR467, Pt B, Ch 4, Sec 2, Tab 1.

1.2 Aluminium structures

1.2.1 In many cases, aluminium structures are used for special areas on passenger ships, mostly on higher decks of the superstructures.

Special attention is to be paid to the following items:

- aluminium is to be treated differently than steel structure regarding welding procedure, welding conditions and strength behavior
- aluminium material designation and properties are to be submitted by the designer
- connection between aluminium and steel structure in order to assess properly the efficiency of the longitudinal strength
- in case of bimetallic joints, these parts have to be certified.

1.2.2 Aluminium structures are to be checked according to NR467, Pt B, Ch 4, Sec 1, [4].

2 Specific loads

2.1 General

2.1.1 Design loads to be applied for structural assessment are defined in NR467, Pt B, Ch 5.

Specific considerations for application of those loads to passenger ships and ro-ro passengers ships are detailed in [2.3] to [2.4].

2.2 Hull girder loads

2.2.1 Due to the slender hull shape and light cargo weight, passenger ships and ro-ro ships are usually always in hogging in still water condition. Since the variation in cargo distribution is usually very low, the still water bending moment does generally not vary much.

As a consequence, design values of still water bending moment are generally given as a maximum and a minimum value in hogging condition (together with the related distribution).

This allows to reduce the maximum sagging value at sea and therefore to limit possible buckling issues in the upper part of the ship.

2.3 External loads

2.3.1 Exposed decks

External pressures to be considered for the calculation of exposed decks scantlings are defined in NR467, Pt B, Ch 5, Sec 5, [6.1].

2.4 Internal loads

2.4.1 Flooding

Flooding pressure to be used for the assessment of watertight structures is defined in NR467, Pt B, Ch 5, Sec 6, [1.4].

The freeboard deck and hatches included in the freeboard deck are to be checked with flooding pressure acting from below the deck, based on the deepest equilibrium waterlines submitted by the designer.

2.4.2 Technical spaces

In case no specific value has been submitted by the designer for loads in technical spaces, the rule value defined in NR467, Pt B, Ch 5, Sec 6, Tab 10 is to be used.

Technical spaces include the following areas:

- AC-Rooms
- all stores except stores dedicated for ropes (for which the rule value defined for "other accommodation compartments" in NR467, Pt B, Ch 5, Sec 6, [6] is to be considered)
- engine control room
- workshops
- galley/Pantry
- laundry
- luggage handling area.

3 Bending efficiency

3.1 Principle

3.1.1 For architectural reasons, structural connections between decks of passenger ships are generally reduced to the minimum in public areas. In addition, the hull girder behaviour is impacted by typical design specificities, such as:

- recess in way of life boats
- large openings in the side shell (windows)
- openings in longitudinal bulkheads
- simple pillar connections between decks over large areas.

As a result, the shear deformation between decks is no longer negligible, and standard beam theory hypothesis assuming that out-of-plane deformation of beam sections is negligible is no longer valid.

This phenomenon is taken into account considering bending efficiencies for each deck. Bending efficiencies describe in percentage how much a structure contributes to the longitudinal hull girder strength. The percentages are used as follows:

- when calculating hull girder inertia and modulus at bottom and deck, contribution of a given deck is weighted by its bending efficiency and,
- when evaluating hull girder stress in one deck, the stress is weighted by the bending efficiency.

The bending efficiencies of decks are linked to the global behavior of the ship. Hence they cannot be properly evaluated without a complete finite element model of the ship.

3.1.2 Bending efficiencies are used in 2D assessment.

3.2 Calculation

3.2.1 When a complete ship model is available, the bending efficiency of each deck is to be determined (usually by dichotomy) so that, subjected to a given vertical bending moment, the longitudinal stress computed in the 2D model matches as close as possible the longitudinal stress on the complete ship model calculated with the methodology described in App 1, [6].

3.2.2 When a complete ship model is not available, two extreme sets of bending efficiencies are to be applied for each deck and longitudinal bulkhead. These two sets are either to be obtained with 2D beam theory taking into account the shear deformation in panels or to be based on similarities with previous projects.

If a 2D calculation is performed, pillars, window jambs and all other elements non continuous in the longitudinal direction are to be modeled as continuous panels, with an equivalent thickness calculated according to the formula defined in NR467, Pt B, Ch 6, Sec 1, [1.3.2].

4 Plating

4.1 Plating under fork lift trucks

4.1.1 Deck plates on passenger ships are generally subject to uniform loads from accommodation, tank liquids and sea pressure.

However, attention is to be paid to areas in which fork lift trucks are used for handling of stores, luggage etc. These areas are to be reviewed against wheel loads in accordance with NR467, Pt B, Ch 7, Sec 4, [3].

4.2 Buckling

4.2.1 Buckling of plates is to be carefully checked. Several areas are typically critical:

- the engine room is generally designed with transverse framing and is typically located close to the midship area where the maximum bending moment occurs
- thin plates are used in upper areas, where local loads are low but hull girder stress can be high
- decks and casing of ro-ro passenger ships are subject to racking loads (see App 4).

4.3 Openings

4.3.1 Deck

Decks of passenger ships and ro-ro passenger ships are typically pierced with several openings due to stairs, lift, ventilation, casing, ramps, etc. Therefore, attention is to be paid to the local stress concentration in way of opening corners.

For ships for which a complete ship FE model is not available, the following procedure may be used to evaluate the required plate thickness in way of opening corners:

- Determine the stress concentration factor k_1 in way of opening corners either from literature or from a FE model.
- Calculate the longitudinal stress σ_L, in N/mm² according to NR467, Pt B, Ch 6, Sec 1, [2.1].

  In case more accurate stress levels are available (e.g. FEM) they can also be used as nominal stress.
- Calculate the local stress σ_{local}, in N/mm²:

  $\sigma_{local} = \sigma_L \cdot k_1$
- Calculate the admissible stress σ_{perm}, in N/mm², as per NR467, Pt B, Ch 6, Sec 1, [3.5.1] for the bending assessments.

  where:

  R_{eH} : Minimum yield stress, in N/mm², of the plating material, defined in NR467, Pt B, Ch 4, Sec 1, [2]
- Calculate the required net plate thickness t_{req}, in mm.

  $t_{req} = t_{act} \cdot \sigma_{local} / \sigma_{perm}$

  where:

  t_{act} : Actual net thickness of the plating, in mm.

An accurate finite element model of the deck opening may also be used to directly compare the stress levels in the element in way of opening corners with the rule admissible stress levels depending on the size of the mesh, according to NR467, Pt B, Ch 8, App 2.

4.3.2 Longitudinal bulkhead

Particular attention is to be paid to openings in longitudinal bulkheads, since the hull girder stiffness above the bulkhead deck is mainly ensured by them. In addition, these openings are often located in specific areas like stair cases and/or lifts. The stress in way of these openings is to be obtained by a complete ship FE model and local reinforcements in way of these openings are to be carefully checked.

However, for ships for which a complete ship FE model is not available, the stress concentration in way of opening corners in longitudinal bulkheads contributing to the hull girder strength may be checked as described for deck openings.

4.3.3 Superstructure side - frames between windows

Hull girder deformations resulting from vertical bending moment induce relative horizontal displacement of decks. This implies possible high shear stress in the vertical frames between windows.

The stress level in way of vertical frames may be evaluated either with a complete ship FE model (see App 1) or a partial FE model (see App 2), or by simplified direct calculation method based on the equivalent thickness defined in NR467, Pt B, Ch 6, Sec 1, [1.3.2].

In the case of an isolated beam structural model, the stress in the window jamb is to be calculated based on the following boundary conditions:

- the vertical beam between two adjacent window openings (window jamb) is fully fixed at the lower end
- at the upper end, the beam is fixed for rotation around all three axis, fixed for translation in y and z-direction and free for translation in x-direction.

Stress levels in web frames between windows may be obtained through the following steps:

a) Calculate the equivalent thickness t_{eq}, in mm, with the formula given in NR467, Pt B, Ch 6, Sec 1, [1.3.2], of the whole longitudinal structure of the ship at the level of the considered window jamb.

b) Create a section in a 2D modeling software, taking into account the actual height of the window opening h_{JAMB}, in m and the equivalent thickness t_{eq} calculated above, in way of the window opening.

c) Calculate with the 2D modelling software the hull girder shear stress τ_{2D}, in N/mm², induced by a given value of vertical shear force Q_{2D}, in kN, in way of the window.

d) Calculate the total acting force Q_{TOTAL}, in kN:

   $Q_{TOTAL} = Q_{sw} + Q_{wv-LC}$

   where:

   Q_{sw} : Design still water shear force, in kN, defined in NR467, Pt B, Ch 5, Sec 4, [2.3.1]

   Q_{wv-LC} : Vertical wave shear force, in kN, defined in NR467, Pt B, Ch 5, Sec 4, [3.6.4]

e) Calculate the hull girder shear stress τ, in N/mm², in way of the window:

   $\tau = \tau_{2D}/Q_{2D} \cdot Q_{TOTAL}$

f) Calculate the horizontal force F_{JAMB}, in kN, acting on the windows web frame:

$F_{JAMB} = \tau \cdot t_{EQ} \cdot \ell_P$

where:

ℓ_p : Longitudinal distance between two adjacent window jambs, in m.

g) Calculate the shear stress τ_{JAMB}, in N/mm², in the window jamb:

$\tau_{JAMB} = 10 \cdot F_{JAMB}/A_{JAMB}$

where:

A_{JAMB} : Net shear area, in cm², of the window jamb.

h) Calculate the bending moment M_{JAMB}, in kN.m in the window jamb:

$M_{JAMB} = F_{JAMB} \cdot h_{JAMB}/2$

i) Calculate the bending stressσ_{JAMB}, in N/mm², in the window jamb:

$\sigma_{JAMB} = 1000 \cdot M_{JAMB}/Z_{JAMB}$

where:

Z_{JAMB} : Net section modulus, in cm³, of the window jamb.

j) Calculate the combined stress $\sigma_{VM\ JAMB}$, in N/mm², in the window jamb:

$$\sigma_{VMJAMB} = \sqrt{\sigma_{JAMB}^2 + 3\tau_{JAMB}^2}$$

4.4 Specificities of ro-ro passenger ships and ro-ro cargo ships

4.4.1 General

Plating on ro-ro decks is subject to wheel loads from different kinds of vehicles and is therefore to be checked in accordance with NR467, Pt B, Ch 7, Sec 4, [3].

Specific attention is to be given to the following items:

- type of tyres (pneumatic or solid rubber)
- tyre print area (if not known refer to NR467, Pt B, Ch 7, Sec 4, [3.3.2]
- Transverse stowage and turn around areas (cases where one axle of transversally orientated vehicles may be entirely supported by a single EPP)
- are trailer without truck supported by resting pads only (without wood below) or by another supporting device?
- are some vehicles used only in harbours?

4.4.2 Fatigue

Fatigue assessment due to loading/unloading sequences may be required.

Governing parameters are in particular:

- use AH36-grade with thinner plate scantlings than A-grade, which reduces the fatigue life
- rate of vehicles driving on/off the ship per day
- width of the passage area for the vehicles (are the vehicles always driving over the same small area?).

5 Ordinary stiffeners

5.1 Ordinary stiffeners sustaining wheel loads

5.1.1 Stiffeners submitted to wheel loads are to be checked in accordance with NR467, Pt B, Ch 7, Sec 5, [1.2].

In case of design loads with multiple axle trailers, direct calculation with 3D analysis as per NR467, Pt B, Ch 7, Sec 5, [1.2.5] is recommended. For such calculation, different positions of the wheel loads are to be considered to maximize the bending moment and the shear force in the stiffener.

In accordance with NR467, Pt B, Ch 5, Sec 6, [7], the inertial loads due to vertical acceleration is to be weighted by a coefficient α = 0,5 in order to account for the effect of the vehicle shock absorber. In case of vehicle without shock absorber (typically tracked vehicle or trailer without tug master and resting on support, etc...), α is to be taken equal to 1.

5.1.2 Special considerations regarding multispan ordinary stiffeners subjected to wheeled loads are detailed in NR467, Pt B, Ch 7, Sec 5, [1.2.5].

5.1.3 Special attention is to be paid to the connection of the ordinary stiffener to the primary deck structure located close to a wheel load point.

In case of heavy wheel loads, collar plate might be required in order to provide a better connection and to increase the shear area.

5.1.4 Requirements regarding welding of connections of stiffeners subjected to wheel loads are given in NR467, Pt B, Ch 13, Sec 3, [3.2.4].

5.2 Ordinary stiffeners in way of life saving appliances

5.2.1 Deck stiffeners in way of launching appliances used for survival craft or rescue boat are to be checked with a reduced admissible combined stress in accordance with NR467, Pt B, Ch 7, Sec 5, [1.5].

6 Primary members

6.1 General

6.1.1 According to NR467, Pt B, Ch 7, Sec 6, [1.1.2], a complete model is compulsory for the review of ships having a length L greater than 150 m.

For passenger ships of length L less than 150 m, the need for a complete ship model should be agreed with the society at the very beginning of the project on a case by case basis.

According to NR467, Pt D, Ch 11, Sec 3, [5.1] and NR467, Pt D, Ch 12, Sec 3, [5.1], a complete ship model is required for the review of primary members of ships complying with one of the following criteria:

- multi decks ship having series of openings in the side shell and/or longitudinal bulkheads, when the stress due to the different contributions of each deck is to be taken into account
- when the size of openings in the side shell and/or longitudinal bulkheads located below the deck assumed by the designer as the strength deck decrease significantly the capability of the plating to transmit shear force to the strength deck
- when the ends of superstructures which are required to contribute to longitudinal strength may be considered not effectively connected to the hull structure.

6.1.2 The structural review of primary members is to be carried out according to:

- requirements of App 1 for ships analysed through complete ship models
- requirement [6.1.3] for ships analysed through partial 3D beam models.

6.1.3 Partial 3D beam model

a) As a first step, a partial model covering at least 3 web frame spacings is to be created.

   This model is to be in accordance with the structure arrangement of midship area.

   Furthermore, the model is to be supported in way of the bilge and subdivision bulkhead. Symmetry conditions are to be applied at each end of the model.

   All the applicable design load sets defined in NR467, Pt B, Ch 7, Sec 2 are to be considered.

b) In addition to this model, where the structure differs from midship arrangement, local 3D beam model may be required to review the deck primary structure.

   For such models, attention is to be paid to the efficiency of supports below the considered deck and to the extent of the model, which is to be sufficient to reach elements where boundary conditions can be clearly defined.

   In all cases where uncertainties exist on supports or boundary conditions the model is to be built using conservative assumptions.

c) Isolated 2D beam calculations is to be performed where the structural arrangement is simple and the boundary conditions can be easily defined.

Particularly in larger passenger and ro-ro passenger ships, it is important to define which bulkheads are contributing to the vertical structural strength and which are only secondary accommodation bulkheads.

6.2 Racking analysis

6.2.1 Passenger ships

Transverse bulkheads and primary structural members of ships analysed through complete ship model are to be checked against racking according to App 1.

6.2.2 Ro-ro passenger ships and ro-ro cargo ships

Due to their specific bulkheads arrangement, ro-ro passenger ships are generally sensitive to transversal loads such as sea pressure on side shell in beam sea condition or inertial loads due to transverse acceleration.

Therefore the strength of structure above the bulkhead deck under transversal loads is to be carefully investigated for this type of ship.

The racking behaviour is considered as a global behaviour and is usually highly dependent on the following key factors:

- connection of decks to the front bulkhead (bow door or not) and the transom bulkhead
- structural continuity of transverse/vertical members through the freeboard deck.

Primary members of ro-ro passenger ships are also to be checked against racking behaviour according to:

- App 1 for ships analysed through a complete ship model
- App 4 for ships for which a complete ship model is not available

6.3 Primary members sustaining wheel loads

6.3.1 As a general rule, when reviewing primary structure, wheel loads due to truck stowage may be considered as point loads and are to be applied taking into account the design load and the arrangement of the trailer submitted by the designer, in order to maximize the reactions on the different beams. Situations in loading or unloading the ship are also to be considered.

Wheel loads due to car stowage may be considered as distributed loads.

In case of partial 3D beam model, as secondary stiffeners are not modeled, wheel loads are to be directly applied on deck beams and deck girders. Particular attention is to be paid to the distribution of the load on the transverse deck beams.

Possible reduced shear areas due to openings in primary structural members are to be taken into account in the calculation.

6.4 Primary members in way of life saving appliances

6.4.1 Deck primary members in way of launching appliances used for survival craft or rescue boat are to be checked with a reduced admissible combined stress in accordance with NR467, Pt B, Ch 7, Sec 6, [2.4].

6.5 Connection between side shell web frame and deck beam in ro-ro spaces

6.5.1 Side shell web frames and deck beams are generally connected without brackets in ro-ro spaces. The stress in the flange of deck beams is therefore transferred by shear in the common web part of the deck beam and side shell frame.

This connection is always a critical point due to high stress in the deck beam flange and low side shell frame height in order to maximize ro-ro spaces (see App 4, [2.1]).

The thickness of the common part of the web required to support shear stress is to be evaluated with formula given in NR467, Pt B, Ch 4, Sec 5, [4.5].

6.5.2 Welding

Structural continuity of the flange of vertical members downwards is to be ensured.

In case of tensile stress, the continuity is to be ensured by using full penetration welding, or fillet welding providing that the effective fillet weld area complies with the requirements of NR467, Pt B, Ch 13, Sec 3, [5.2].

Connections subject to tensile stress are also to be checked according to NR467, Pt B, Ch 4, Sec 1, [2.6].

6.6 Pillars

6.6.1 Pillars are extensively used on passenger and ro-ro passenger ships. They transfer the load from upper decks downwards, but are also loaded due to the hull deformation. It is critical to evaluate if the pillar works always in compression or if the pillar is also subject to traction forces.

For each pillar, special attention is to be paid to the following items (see NR467, Pt B, Ch 4, Sec 5, [11]):

- for pillars in tension:
  - doubling plates at connections with decks are not allowed
  - z-quality steel is to be applied for the deck plating and deck girders/beams, in case their out plane stress level is higher than 0,5 R_y. Alternatively ultra-sonic-testing of the deck plating before and after the welding may be requested
  - in case fillet welding is used, the effective fillet weld area is to comply with the requirements of NR467, Pt B, Ch 13, Sec 3, [5.2].
- structural continuity of pillars from above further down
- transmission of stress through the deck
- buckling (see NR467, Pt B, Ch 9, Sec 1 and NR615)
- thickness of doubling plates. (for pillars in compression)
- no hollow profiles allowed in tanks.

7 Fatigue analysis

7.1 General

7.1.1 Ordinary stiffeners end connections are to be assessed in fatigue according to NR467, Pt B, Ch 10, Sec 1 and NI611.

7.1.2 Where deemed necessary, structural discontinuities in longitudinal members and corners of large openings are also to be checked according to App 2, [5].

Appendix 1 Finite Element Analysis based on Complete Ship Models

Symbols

The following symbols are defined in NR467, Part B:

B : Moulded breadth, in m

C : Wave coefficient

C_B : Block coefficient

H : Wave parameter

L : Rule length, in m

L_{aft} : Distance, in m, between the aft end of the complete ship model and the aft rule end of the ship

L_{fore} : Distance, in m, between the fore end of the ship defined in Rules and the fore end of the complete ship model

n : Navigation coefficient

T : Moulded draught, in m

x : Longitudinal position along the ship, defined in Rules coordinates

The following symbols are defined in this Guidance Note:

L_{aft-pp} : Distance, in m, between the aft end of the complete ship model and the aft perpendicular

$L_{fore-pp}$: Distance, in, between the fore perpendicular of the ship and the fore end of the complete ship model

L_{pp} : Length between perpendiculars, in m

X : Longitudinal position along the ship, in m, defined from the aft perpendicular

$\alpha = L_{aft}/L$

$\alpha_{pp} = L_{aft-pp}/L_{pp}$

$\beta = L_{fore}/L$

$\beta_{pp} = L_{fore-pp}/L_{pp}$.

1 General

1.1 Objective and scope

1.1.1 This Appendix is a guidance for the assessment of primary supporting members using a finite element complete ship model.

1.1.2 The structural analysis aims at:

- assessing the ship longitudinal strength for ships with service notation **passenger ship**, **ro-ro-passenger ship** or **ro-ro cargo ship** and/or when a 2D methodology is deemed not sufficient
- calculating stresses in the primary supporting members and in the longitudinal and transverse elements to be used for yielding and buckling checks.

1.2 Definitions

1.2.1 Shell elements

In the context of this Appendix, a shell element is a 3 or 4 node finite element or a 6 or 8 node quadratic finite element acting in traction, compression, bending and warping.

1.2.2 Rod and bar elements

In the context of this Appendix, the following definitions are assumed:

- rod element means 2 node line finite element acting with traction and compression only
- bar element means a rod element acting also in flexion and torsion, and having constant properties along the length of the element.

1.2.3 Rigid interpolation element

A rigid interpolation element is an element linking a dependent node with several independent nodes, where the displacement of the dependent node is controlled by the weighted average of the independent nodes. Therefore, the loads applied on the dependent node will result in such a load distribution on the independent nodes as to respect the quasi-static equilibrium of the element.

1.3 Strength analysis procedure

1.3.1 Procedure description

The structural finite element analysis is performed as follows:

- the complete ship is modeled as described in Article [2]
- the application of loads and boundary conditions as well as stress calculation methods depend on the type of analysis, as described in [1.3.2]
- strength is assessed as defined in Article [5]
- bending efficiencies are assessed according to Sec 3, [3.2.1] with the conditions defined in Article [6]. Bending efficiencies are then reinjected in the 2D calculations.

1.3.2 Types of analysis

Two types of analyses are dealt with in this Appendix:

- rule-load-based analysis

  Prescriptive loads as defined in the Rules are applied to the model. Methodology for load application, boundary conditions and stress calculation is given in Article [3]
- direct hydrodynamic-load-based analysis.

  The loads derive from direct sea-keeping analysis of the ship. Methodology for load application, boundary conditions and stress calculation is given in Article [4].

The whole structural analysis is generally based on a rule-load-based analysis, as the accommodation deck loads are not taken into account in a direct-hydrodynamic-load-based analysis.

Additionally, if deemed relevant, a direct-hydrodynamic-load-based analysis may be performed so as to focus on the direct load effects such as racking. In particular, this is to be applied when the stiffness of transverse bulkheads below the bulkhead deck is low and induces a non-negligible transverse deformation.

2 Structural model

2.1 Extent of the model

2.1.1 The complete ship is to be modeled so that the elements contributing to longitudinal strength or leading to shear deformation are properly taken into account.

2.2 Finite element types

2.2.1 Shell elements are to be used to represent plating.

2.2.2 Ordinary stiffeners are to be modeled with bar elements. The eccentricity of the neutral axis is to be modeled.

2.2.3 Webs of primary supporting members are to be modeled with shell elements, including those of deck primary structure and web frames.
Face plates of primary structure may be modeled with rod or bar elements.

2.3 Model construction

2.3.1 All the main longitudinal and transverse structural elements constituting the primary structure are to be modeled.

Ordinary stiffeners are to be modeled.

2.3.2 Special attention is to be brought to the following structural elements which are to be correctly represented:

- deck structure, with particular attention to deck openings
- transverse and longitudinal bulkheads, with particular attention to door openings
- transverse web frames
- pillars
- vertical stiffeners in way of windows
- ends of superstructure and their fixation to deck
- side shell openings.

2.3.3 The following structural elements may be disregarded:

- small deck openings (less than typical size of elements)
- openings in webs of primary supporting members when their height is less than 50% of the web height, provided that a detailed analysis is performed for the assessment of these primary supporting members
- openings in webs of decks primary supporting members when their height is more than 50% of the web height, provided that a local fine mesh analysis is performed for the assessment of these primary supporting members.

2.4 Structural modeling

2.4.1 Aspect ratio

Aspect ratio of shell elements is generally not to be greater than 2, and in no case greater than 4.

Angles of quadrilateral elements are to be greater than 60° and less than 120°. Angles of triangular elements are to be greater than 30° and less than 120°.

2.4.2 Mesh size

The shell element mesh is to follow the stiffening system as far as practicable, hence representing the actual plate panels between stiffeners.

In order to account for the shear deformation of deckhouses and superstructure sides, at least three elements in each direction of the strips between the windows are to be modeled.

The web of double skin structures is to be modeled with at least three elements in height.

2.4.3 Pillars

Pillars may be modeled by bar elements. Their bending properties and their connections to deck are to be accurately represented.

2.4.4 Corrosion

All the elements are to be modeled with their net thickness, as per Rules.

2.4.5 Lightweight and deadweight distribution

For direct-hydrodynamic-load-based analysis and for racking load case performed by rule-load-based analysis, the finite element model is to include both the lightweight and the deadweight mass and inertia distributions.

The lightweight may be adjusted, by modification of the material density properties of shell and bar elements.

The deadweight distribution on passenger ships is generally very light (mainly passengers and small capacities) and may be modeled similarly to the lightweight, by modification of the material density properties of shell and bar elements.

3 Rule-load-based analysis

3.1 General

3.1.1 Application

This Article describes the methodology to be applied for the application of the prescriptive loads defined in the Rules, the description of the associated boundary conditions, and the stress calculation.

3.1.2 Procedure for load application and boundary condition

The rule-load-based analysis is based on a superimposition method, and stresses are to be calculated as follows:

- hull girder stresses are to be calculated with load application and boundary conditions defined in [3.2] and with load distributions defined in [3.3]
- local stresses are to be calculated with load application and boundary conditions defined in [3.4].

Hull girder stresses and local stresses are summed for different relevant load combinations, as defined in [3.5].

3.2 Hull girder stress calculation

3.2.1 General

Calculation of hull girder stresses is to be performed for the HVM, FVM, OHM, OHS, OVA and BP dynamic load cases as defined in NR467, Pt B, Ch 5, Sec 2, [2] in accordance with:

- the load approach defined in [3.2.2]
- the boundary conditions defined in [3.2.5].

3.2.2 Load approach

Hull girder stresses are obtained by applying longitudinal distribution of the vertical or horizontal loads. These longitudinal distributions are hereafter referred to as hull girder load distributions and might be defined as:

- vertical or horizontal load distribution VL(x)
- shear force distribution SF(x):

$$SF(x) = \int_{X\ \text{aft boundary}}^{X} VL(t)dt$$

- bending moment distribution BM(x):

$$BM(x) = \int_{X\ aft\ boundary}^{X} SF(t)dt$$

These three definitions are totally equivalent and might equally be used. In this Guidance Note, the hull girder load distributions are defined in [3.2.3], depending on the design parameter they represent. However, they are all to be applied as vertical or horizontal forces, as defined in [3.2.4].

3.2.3 Hull girder load distributions to be applied

Hull girder stresses are to be calculated for the hull girder load distributions described in [3.3].

3.2.4 Application of the loads

Hull girder load distributions are obtained by applying fictitious vertical or horizontal loads at specific longitudinal locations.

The structural elements selected for the application of such loads are to be chosen such as to avoid fictive local stress and generally to be those of high vertical or horizontal stiffness.

3.2.5 Boundary conditions

Hull girder stress calculation is to be performed with the displacement restrictions defined in Tab 1. Rotation of all the nodes is to be free.

Table 1 : Boundary conditions for hull girder stress calculation

Boundary conditions	Displacements in direction		
	X	Y	Z
One node on the fore end of the model	free	fixed	fixed
One node on the port side shell at aft end of the model	fixed	free	fixed
One node on the starboard side shell at aft end of the model	free	fixed	fixed

3.2.6 Overall racking stress calculation

The overall racking stress is to be calculated differently than for the other conditions (local load and flooded ship) by considering the following instead of the vertical and horizontal hull girder loads:

- boundary conditions: every node of the main transverse bulkheads located below the bulkhead deck is to be fixed in x, y and z
- loads: the horizontal acceleration (a_y) defined in Rules for the BR1 dynamic load cases is applied on the material density properties as defined in [2.4.5].

3.3 Hull girder load distributions

3.3.1 Application

Hull girder loads distributions are divided in still water hull girder load distributions and wave hull girder load distributions.

Still water hull girder load distributions are to target the bending moment and shear force admissible distributions.

Admissible distributions might either be defined as:

- realistic distributions (i.e. corresponding to a given loading condition). For such distributions, the methodology described in [3.3.2] should be applied to obtain the set of still water hull girder distributions
- pure envelope distributions (i.e. no loading condition can be found matching these distributions). For these distributions, application of loads might produce convergence issues. Therefore the specific approach proposed in [3.3.3] should be applied.

Admissible distributions corresponding to real loading conditions should be preferred.

3.3.2 Still water hull girder loads obtained from admissible distributions corresponding to specific loading conditions

When admissible distributions correspond to real loading conditions, the following still water distributions are to be considered:

$M_{sw\text{-}max,\ real}$, $Q_{sw\text{-}HOG,\ real}$: Vertical still water bending moment and shear force distributions for the seagoing loading conditions identified as maximizing the hogging behaviour.

$M_{sw\text{-}min,\ real}$, $Q_{sw\text{-}SAG,\ real}$: Vertical still water bending moment and shear force distributions for the seagoing loading conditions identified as minimizing the hogging behaviour or maximizing the sagging behaviour.

$M_{sw\text{-}p\text{-}max,\ real}$, $M_{sw\text{-}p\text{-}min,\ real}$: Vertical still water bending moments for the harbour and tank testing loading conditions identified as maximizing or minimizing the hogging behaviour.

3.3.3 Still water hull girder loads obtained from pure admissible envelope distributions

When admissible distributions do not correspond to specific loading conditions, the still water hull girder loads are to be taken according to the distributions given in items a to c, with:

M_{sw-max}, M_{sw-min}: Permissible vertical still water bending moments in seagoing conditions, defined in NR467, Pt B, Ch 5, Sec 4, [2.2.1]

Q_{sw-max}, Q_{sw-min}: Permissible vertical still water shear forces in seagoing conditions defined in NR467, Pt B, Ch 5, Sec 4, [2.3.1]

$M_{sw-p-max}$, $M_{sw-p-min}$: Permissible vertical still water bending moments in harbour and tank testing conditions defined in NR467, Pt B, Ch 5, Sec 4, [2.2.2]

a) The vertical still water bending moment distributions are to be taken equal to the permissible distributions M_{sw-max} and M_{sw-min} or $M_{sw-p-max}$ and $M_{sw-p-min}$, as applicable, set to 0 at both ends of the model and smoothed to avoid any discontinuity.

b) The vertical still water shear force distribution is to be taken as proposed:

Q_{sw-HOG} : Distribution maximizing still water shear force in hogging defined in Tab 2 and Fig 2

Q_{sw-SAG} : Distribution maximizing still water shear force in sagging defined in Tab 3 and Fig 3.

Note 1: Distribution in sagging is not defined since it is not applicable to ships always in hogging.

c) When the shear properties of the midship area are lower than those of the one third-area and the last third-area, two additional vertical still water shear force distributions are to be applied as proposed:

Q_{sw+} : Distribution maximizing amidship still water shear force defined in Tab 4 and Fig 4

Q_{sw-} : Distribution minimizing amidship still water shear force defined in Tab 4 and Fig 5.

Table 2 : Distribution of hogging still water shear force Q_{sw-HOG}

X **(1)**	Q_{sw-HOG} **(2)**
$-\alpha_{PP}$	0
$-\alpha_{PP}/2$	A_{HOG}
from 0 to 0,4	$Q_{sw-max}(X)$
X_{HOG}	$Q_{sw-HOG}(X_{HOG})$
from 0,6 to 1,0	$Q_{sw-min}(X)$
$1+\beta_{PP}/2$	B_{HOG}
$1+\beta_{PP}$	0

(1) $X = x/L_{PP}$

(2) Values between $X = -\alpha_{PP}$ and $X = 0$, between $X = 0{,}4$ and $X = 0{,}6$ and between $X = 1{,}0$ and $X = 1 + \beta_{PP}$ are to be linearly interpolated.

Note 1:

$$A_{HOG} = (1-\zeta_{HOG})\frac{Q_{sw-max}(X=0)}{2}$$

$$B_{HOG} = (1+\zeta_{HOG})\frac{Q_{sw-min}(X=1)}{2}$$

$$\zeta_{HOG} = \frac{2\varepsilon_{HOG}}{\alpha_{PP}\frac{Q_{sw-max}(X=0)}{2} - \beta_{PP}\frac{Q_{sw-min}(X=1)}{2}} \quad \text{with} \quad |\zeta_{HOG}| \le 0{,}5$$

$$\varepsilon_{HOG} = \alpha_{PP}\frac{Q_{sw-max}(X=0)}{2} + S_{MAX\_AFT} + [0{,}05Q_{sw-max}(X=0{,}4) + Q_{sw-min}(X=0{,}6)] + S_{MIN\_FORE} + \beta_{PP}\frac{Q_{sw-min}(X=1)}{2}$$

$$X_{HOG} = 0{,}5 + \frac{2\varepsilon'_{HOG}}{Q_{sw-min}(X=0{,}6) - Q_{sw-max}(X=0{,}4)} \quad \text{with} \quad 0{,}42 \le X_{HOG} \le 0{,}58$$

$$Q_{sw-HOG}(X_{HOG}) = 5(1-2X_{HOG})\frac{Q_{sw-max}(X=0{,}4) - Q_{sw-min}(X=0{,}6)}{2} - 10\varepsilon_{HOG}$$

$$\varepsilon'_{HOG} = \alpha_{PP}\left[\frac{A_{HOG}}{2} + \frac{Q_{sw-max}(X=0)}{4}\right] + S_{MAX\_AFT} + 0{,}05[Q_{sw-max}(X=0{,}4) + Q_{sw-min}(X=0{,}6)] + S_{MIN\_FORE} + \beta_{PP}\frac{B_{HOG}}{2} + \frac{Q_{sw-min}(X=1)}{4}$$

S_{MAX_AFT} : Area below curve Q_{sw-max} between X = 0 and X = 0,4 as shown in Fig 1

S_{MIN_FORE} : Area above curve Q_{sw-min} between X = 0,6 and X = 1,0 ($S_{MIN\_FORE} < 0$ or $S_{MIN\_FORE} > 0$ if $Q_{sw-min} > 0$), as shown in Fig 1.

Table 3 : Distribution of sagging still water shear force $Q_{sw\text{-}SAG}$

X **(1)**	$Q_{sw\text{-}SAG}$ **(2)**
$-\alpha_{PP}$	0
$-\alpha_{PP} / 2$	A_{SAG}
from 0 to 0,4	$M_{sw\text{-}min}$ (X)
X_{SAG}	$Q_{sw\text{-}SAG}(X_{SAG})$
from 0,6 to 1,0	$M_{sw\text{-}max}$ (X)
$1 + \beta_{PP} / 2$	B_{SAG}
$1+\beta_{PP}$	0

(1) $X = x/L_{PP}$

(2) Values between $X = -\alpha_{PP}$ and $X = 0$, between $X = 0{,}4$ and $X = 0{,}6$ and between $X = 1{,}0$ and $X = 1 + \beta_{PP}$ are to be linearly interpolated.

Note 1:

$$A_{SAG} = (1 - \zeta_{SAG})\frac{Q_{sw-max}(X=0)}{2}$$

$$B_{SAG} = (1 + \zeta_{SAG})\frac{Q_{sw-max}(X=1)}{2}$$

$$\zeta_{SAG} = \frac{2\varepsilon_{SAG}}{\alpha_{PP}\frac{Q_{sw-min}(X=0)}{2} - \beta_{PP}\frac{Q_{sw-max}(X=1)}{2}} \quad \text{with} \quad |\zeta_{SAG}| \le 0,5$$

$$\varepsilon_{SAG} = \alpha_{PP}\frac{Q_{sw-min}(X=0)}{2} + S_{MIN\_AFT} + [0,05Q_{sw-min}(X=0,4) + Q_{sw-max}(X=0,6)] + S_{MAX\_FORE} + \beta_{PP}\frac{Q_{sw-max}(X=1)}{2}$$

$$X_{SAG} = 0,5 + \frac{2\varepsilon'_{SAG}}{Q_{sw-max}(X=0,6) - Q_{sw-min}(X=0,4)} \quad \text{with} \quad 0,42 \le X_{SAG} \le 0,58$$

$$Q_{sw-SAG}(X_{SAG}) = 5(1 - 2X_{SAG})\frac{Q_{sw-min}(X=0,4) - Q_{sw-max}(X=0,6)}{2} - 10\varepsilon_{SAG}$$

$$\varepsilon'_{SAG} = \alpha_{PP}\left[\frac{A_{SAG}}{2} + \frac{Q_{sw-min}(X=0)}{4}\right] + S_{MIN\_AFT} + 0,05[Q_{sw-min}(X=0,4) + Q_{sw-max}(X=0,6)] + S_{MAX\_FORE} + \beta_{PP}\frac{B_{SAG}}{2} + \frac{Q_{sw-max}(X=1)}{4}$$

S_{MAX_FORE} : Area below curve $Q_{sw\text{-}max}$ between X = 0,6 and X = 1,0 as shown in Fig 1

S_{MIN_AFT} : Area above curve $Q_{sw\text{-}min}$ between X = 0 and X = 0,4 ($S_{MIN\_AFT} < 0$ or $S_{MIN\_AFT} > 0$ if $Q_{sw\text{-}min} > 0$), as shown in Fig 1.

Table 4 : Amidship positive and negative still water shear forces Q_{sw+} and Q_{sw-}

X **(1)**	Q_{sw+} **(2)**	Q_{sw-} **(2)**
0	0	0
0,1	G_+	G_-
0,2	G_+	G_-
0,3	0	0
from 0,4 to 0,6	$Q_{sw\text{-}max}$ (X)	$Q_{sw\text{-}min}$ (X)
0,7	0	0
0,8	G_+	G_-
0,9	G_+	G_-
1,0	0	0

(1) $X = x/L_{PP}$

(2) Values between X = 0 and X = 0,4 and between X = 0,6 and X = 1,0 are to be linearly interpolated.

Note 1:

$G_+ = -2{,}5\ S_{MAX\_MID} - 0{,}125\ [Q_{sw\text{-}max}(X=0{,}4) + Q_{sw\text{-}max}(X=0{,}6)]$

$G_- = -2{,}5\ S_{MIN\_MID} - 0{,}125\ [Q_{sw\text{-}min}(X=0{,}4) + Q_{sw\text{-}min}(X=0{,}6)]$

S_{MAX_MID} : Area below curve $Q_{sw\text{-}max}$ between X=0,4 and X=0,6 as shown in Fig 1

S_{MIN_MID} : Area above curve $Q_{sw\text{-}min}$ between X=0,4 and X=0,6 ($S_{MIN\_MID} < 0$ or $S_{MIN\_MID} > 0$ if $Q_{sw\text{-}min} > 0$), as shown in Fig 1.

Figure 1 : Definition of areas from design still water shear force envelope distributions

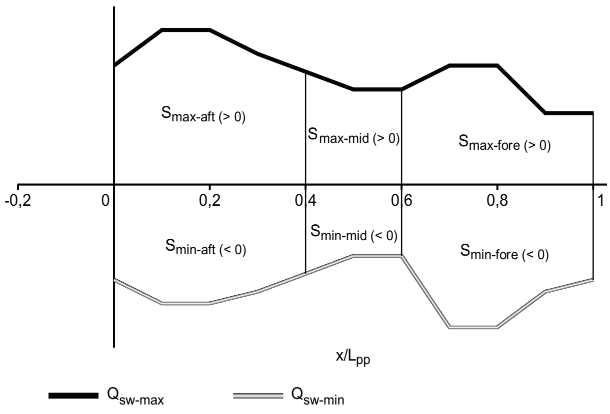


Figure 2 : Distribution of hogging still water shear force Q_{sw-HOG}

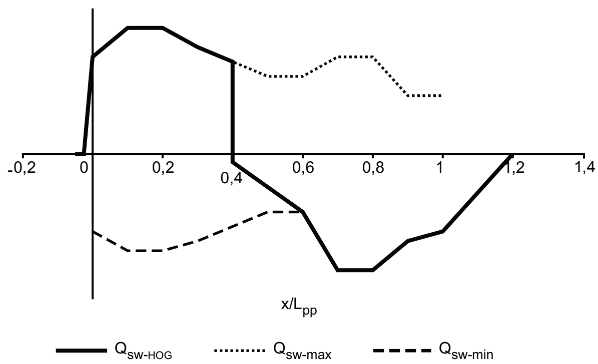


Figure 3 : Distribution of sagging still water shear force Q_{sw-SAG}

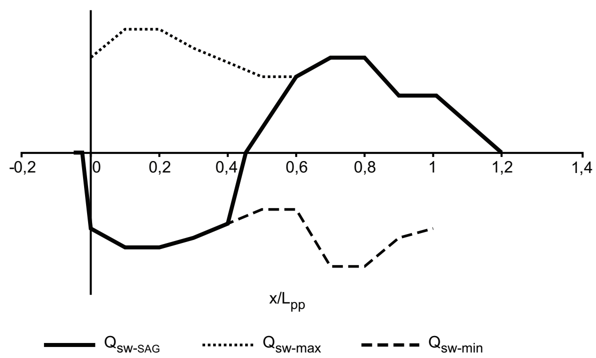


Figure 4 : Amidship positive still water shear force Q_{sw+}

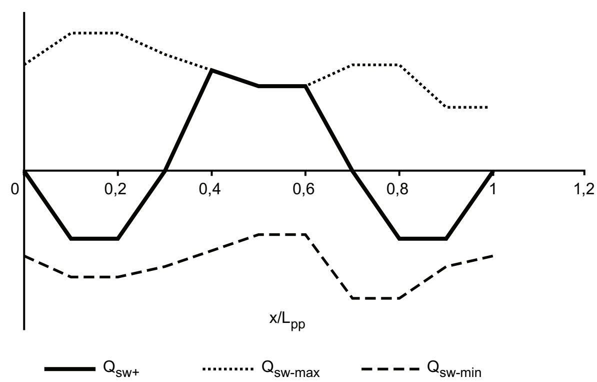


Table 5 : Asymmetrical distributions F'_Q

x/L	F'_Q for WVL_H	F'_Q for WVL_S
$-\alpha$	0	0
$-\alpha/2$	$a\,\gamma$	$-a$
α'	$a\,\gamma$	$-a$
0,20	0,92 γ	0,92
0,30	0,92 γ	0,92
0,40	0,70	0,70
0,45	1,707 γ – 1,05	0,657
0,50	0	0
0,70	$-\gamma$	1,0
0,85	$-\gamma$	1,0
$1-\beta'$	$-b\,\gamma$	b
$1+\beta/2$	$-b\,\gamma$	b
$1+\beta$	0	0

Note 1:

$$\gamma = 190\frac{C_B}{110(C_B+0,7)}$$

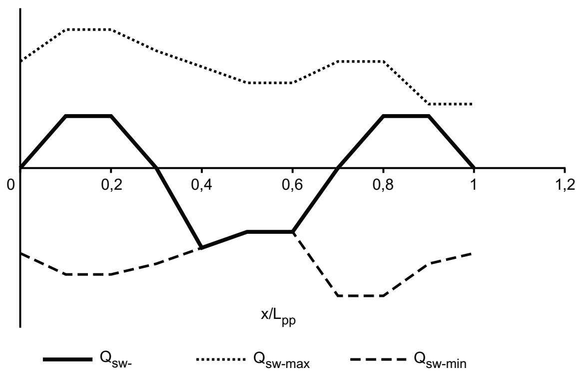
$$a = -3,45\alpha + \sqrt{(3,45\alpha)^2 + 0,466}$$

$$b = -5\beta + \sqrt{(5\beta)^2 + 0,547}$$

$$\alpha' = 0,2\frac{a}{0,92}$$

$$\beta' = 0,15\frac{b}{\gamma}$$

Figure 5 : Amidship negative still water shear force Q_{sw-}



3.3.4 Vertical wave hull girder loads

The vertical wave bending moments in hogging and sagging conditions M_{wv-h} and M_{wv-s}, and the positive and negative vertical wave shear forces Q_{wv-pos} and Q_{wv-neg} are to be taken as defined in NR467, Pt B, Ch 5, Sec 4, [3] for strength assessment.

Vertical wave hull girder loads are defined so as to match rule extreme values for both rule vertical wave shear force and rule vertical wave bending moment. These vertical wave hull girder loads are expressed in terms of shear force.

The vertical wave shear force for each dynamic load case at any longitudinal position is to be taken according to the following formula:

$$Q_{wv-LC} = 30\,|C_{QV}|\,F'_Q\,n\,C\,L\,B\,(C_B + 0,7)\,10^{-2}$$

with:

- C_{QV} : Load combination factor for the strength assessment, depending on the considered dynamic load case and as defined in NR467, Pt B, Ch 5, Sec 2, [2.2.1]
- F'_Q : Distribution factor defined for the four following distributions:
  - WVL_H : Distribution maximizing wave bending moment and shear force in hogging with F'_Q defined in Tab 5 and Fig 6
  - WVL_S : Distribution maximizing wave bending moment and shear force in sagging with F'_Q defined in Tab 5 and Fig 7
  - WVL_+ : Distribution maximizing the amidship positive wave shear force with F'_Q defined in Tab 6 and Fig 8
  - WVL_- : Distribution maximizing the amidship negative wave shear force with F'_Q defined in Tab 6 and Fig 9.

Figure 6 : Nondimensional hogging wave shear force distribution

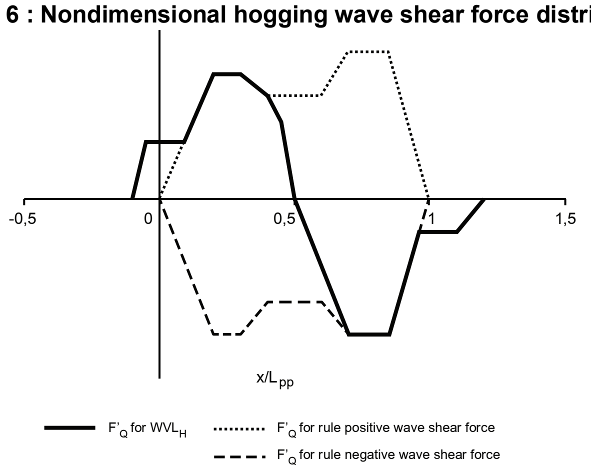


Figure 7 : Nondimensional sagging wave shear force distribution

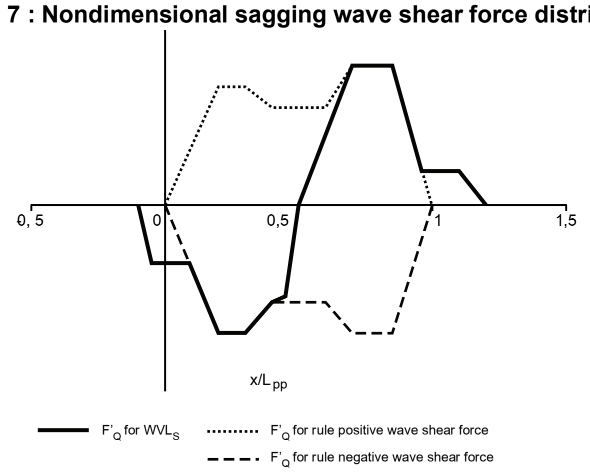


Figure 8 : Nondimensional positive amidship wave shear force distribution

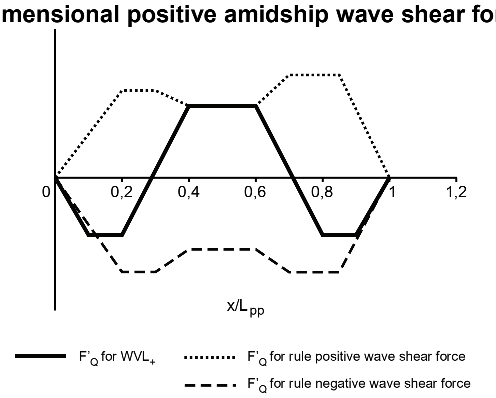
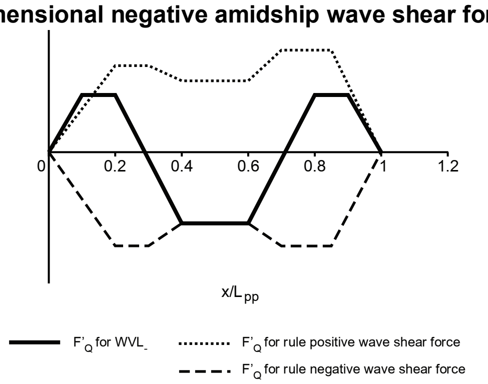


Table 6 : Symmetrical distributions F'_Q

x/L	F'_Q for WVL_-	F'_Q for WVL_+
$-\alpha$	0	0
0	0	0
0,1	+ 0,56	− 0,56
0,2	+ 0,56	− 0,56
0,4	− 0,70	+ 0,70
0,6	− 0,70	+ 0,70
0,8	+ 0,56	− 0,56
0,9	+ 0,56	− 0,56
1,0	0	0
$1 + \beta$	0	0

Figure 9 : Nondimensional negative amidship wave shear force distribution



3.3.5 Horizontal wave hull girder loads

The wave horizontal hull girder loads WHL, including the horizontal wave bending moment M_{wh} and the horizontal wave shear force Q_{wh} are defined in terms of shear force in order to match the rule extreme values.

The horizontal wave shear force for each dynamic load case at any longitudinal position is to be taken according to the following formula:

- for $0 < x < L$:

$$Q_{wh-LC} = 32 \cdot \frac{M_{wh-LC}}{L} \cdot \left[\frac{x}{L} \cdot \left(\frac{x}{L} - 1\right) \cdot \left(2\frac{x}{L} - 1\right)\right]$$

- for $x \leq 0$ and $x \geq L$:

$Q_{wh\text{-}LC} = 0$

with:

$$M_{wh-LC} = f_\beta \cdot C_{WH} \cdot 2,6 \cdot f_R \cdot f_S \cdot f_{nl} \cdot H \cdot L^3 \cdot C_{B-LC}^{0,3} \cdot \left(\frac{T_{LC}}{L}\right)^{0,8}$$

f_β, f_R, f_S, f_{nl}, H, $C_{B\text{-}LC}$, T_{LC}, C_{WH} : parameters defined in NR467, Pt B, Ch 1, Sec 3 and in NR467, Pt B, Ch 5, Sec 3 and Sec 4

3.4 Local stress calculation

3.4.1 Procedure

Calculation of local stresses is to be performed for the following ship conditions:

- local load conditions corresponding to the HVM, FVM, OHM, OHS, OVA and BP dynamic load cases as defined in NR467, Pt B, Ch 5, Sec 2, [2], with loads defined in [3.4.2] and boundary conditions defined in [3.4.3]
- local racking condition, with boundary conditions defined in [3.4.3] and loads defined in [3.4.4]
- flooded ship conditions when a direct calculation for primary supporting members under flooding loads is deemed necessary, with loads defined in [3.4.2] and boundary conditions defined in [3.4.3]
- tank testing

3.4.2 Local loads, tank testing and flooded ship conditions

a) For local load conditions, the following loads defined in the Rules are to be applied:
   - static and dynamic parts of sea pressure
   - static deck loads
   - vertical acceleration applied on deck loads
   - static and dynamic sea pressures on exposed decks. When deemed necessary, an additional calculation disregarding this load is to be performed.

b) For flooded ship conditions, the following loads defined in the Rules are to be applied:
   - still water sea pressures in damaged compartments. The minimum pressures may be neglected.

c) For tank testing condition, the following loads in the Rules are to be applied:
   - testing pressure

3.4.3 Boundary conditions

For local load conditions and flooded ship conditions:

- the displacements of the nodes of the side shell used for the hull girder load balance are to be fixed in x and z direction
- the displacements of the center-line nodes of the bottom and the bulkhead deck are to be fixed in y direction.

3.4.4 Loads for local racking condition

For local racking conditions, the following loads defined in the Rules are to be applied:

- static part of sea pressure on hull
- dynamic part of sea pressure on hull for the BR1 dynamic load cases as defined in NR467, Pt B, Ch 5, Sec 2, [2]
- static deck loads
- vertical acceleration applied on deck loads (mini Rules values) for the BR1 dynamic load cases.

3.4.5 Case of exposed decks with additional deck loads

When an exposed deck is also subject to deck loads, the pressure to be applied is the maximum value between:

- static and dynamic pressure due to deck loads
- wave pressures on exposed deck.

3.5 Stress superimposition

3.5.1 Procedure

In each element of the model, the Von Mises stress is to be calculated for each combination defined in [3.5.4] by superimposing the hull girder stress obtained as per [3.2] with the local stress obtained as per [3.4].

3.5.2 Stress components

The following stress components are to be computed at the centroid of the mid-plane layer of each shell element:

- normal stress σ_1 and σ_2 in the directions of the element co-ordinate system axes
- shear stress τ_{12} with respect to the element co-ordinate system axes.

For rod or bar elements used as face plates of primary supporting members, the following stress components are to be computed:

- axial stress σ_{axial} , calculated based on the axial force.

For bar elements used as pillars or not attached to plating, the following stress components are to be computed:

- axial stress σ_{axial} , based on the axial force alone
- bending stress σ_{bend} , calculated for outermost points of the section profile, based on bending moment only.

3.5.3 Stress superimposition

In each element of the model the combined stress $\sigma_{ij\ total}$(ID) for each component σ_{ij} defined in [3.5.2] is obtained from the following formula:

$$\sigma_{ij\ total}(ID) = \sigma_{ij\ SWHG}(ID) + \sigma_{ij\ WHG}(ID) + \sigma_{ij\ Loc}(ID)$$

where:

$\sigma_{ij\ SWHG}$(ID): Elemental stress calculated for the still water hull girder load case defined in [3.5.4]

$\sigma_{ij\ WHG}$(ID): Elemental stress calculated for the wave hull girder load case defined in [3.5.4]

$\sigma_{ij\ Loc}$(ID): Elemental stress calculated for the local load case defined in [3.5.4].

3.5.4 Load case combinations

Stress calculation is to be performed for the different load case combinations as defined in Tab 7.

4 Direct-hydrodynamic-load-based analysis

4.1 General

4.1.1 Application

The primary structure might be additionally checked using a direct load approach. This is to be regarded as a complement to Article [3]. This article gives a guidance for applying this approach.

4.1.2 Loading condition

One loading condition should be selected among those presented in the loading manual considering the following criteria:

- it represents the maximum draught
- it results in the highest vertical bending moment.

4.1.3 Heavy masses modelling

Heavy masses, such as main engine, are to be modeled by additional nodal masses fitted on the structural model and linked to their supporting structures by a rigid interpolation element.

If massive elements (fuel tanks, ballasts, water tanks) are loaded, they are preferably to be modeled as heavy masses of the lightweight distribution. Wheel loads should be modeled as described in App 3.

Table 7 : Load case combinations

No.	Targeted effect	Still Water Vertical Hull Girder Case (SWHG)**(1)**	Wave Hull Girder Loads (WHG)		Dynamic Load Case (Loc)	Status
			Wave Vertical Hull Girder Case **(1)**	Wave Horizontal Hull Girder Case**(1)**		
HULL GIRDER LOADS AND LOCAL LOADS						
1.1	Maximum positive vertical bending moment (hogging)	$M_{sw\text{-}max}$ or $M_{sw\text{-}max,\ real}$	WVL_H	–	HVM2 FVM2	Mandatory
1.2	Maximum positive vertical bending moment (hogging)	$Q_{sw\text{-}HOG}$ **(5)** or $Q_{sw\text{-}HOG,\ real}$		–		Mandatory
2.1	Maximum negative vertical bending moment (sagging)	$M_{sw\text{-}min}$ or $M_{sw\text{-}min,\ real}$	WVL_S	–	HVM1 FVM1	Mandatory
2.2	Maximum negative vertical bending moment (sagging)	$Q_{sw\text{-}SAG}$ or $Q_{sw\text{-}SAG,\ real}$		–		Mandatory only for ships with possible still water sagging behaviour in seagoing loading condition
3	Maximum positive vertical shear force in the midship area	Q_{sw+} or 0	WVL_+	–	HVM FVM	Mandatory if the shear properties of the midship area are lower than those of the one third-area and the last third-area
4	Maximum negative vertical shear force in the midship area	Q_{sw-} or 0	WVL_-	–	HVM FVM	Mandatory if the shear properties of the midship area are lower than those of the one third-area and the last third-area
5	Maximum negative vertical acceleration	$M_{sw\text{-}max}$ or $M_{sw\text{-}max,\ real}$	WVL_H	WHL	OVA1	Mandatory
6.1	Maximum sea pressure at side	$M_{sw\text{-}min}$ or $M_{sw\text{-}min,\ real}$	WVL_S	WHL	BP2-P	Mandatory
6.2	Maximum sea pressure at side	$Q_{sw\text{-}SAG}$ or $Q_{sw\text{-}SAG,\ real}$				Mandatory only for ships with possible still water sagging behaviour in seagoing loading condition
7.1	Maximum horizontal bending moment	$M_{sw\text{-}max}$ or $M_{sw\text{-}max,\ real}$	WVL_H	WHL	OHM	Mandatory
7.2		$Q_{sw\text{-}SAG}$ or $Q_{sw\text{-}SAG,\ real}$			OHS	Mandatory
RACKING						
8	Maximum transverse acceleration	–	BR1**(2)**	–	BR1**(3)**	Mandatory
TESTING						
9	Testing	$M_{sw\text{-}p\text{-}max}$ or $M_{sw\text{-}p\text{-}max,\ real}$	–	–	Testing**(4)**	Mandatory
FLOODING						
10	Flooding	$M_{sw\text{-}max}$ or $M_{sw\text{-}max,\ real}$	–	–	Flooded**(4)**	Mandatory

(1) See [3.2]
(2) See [3.2.6]
(3) See [3.4.4]
(4) For tank testing and flooding conditions, only the static components are applied.
(5) Attention is to be paid to the fact that the resulting still water vertical bending moment may exceed maximum admissible value $M_{sw\text{-}max}$ in the midship area. Nevertheless, this load combination being meant to assess mostly the fore and aft part where the shear force is dominant, the results in the midship area may be considered with caution.

4.2 Equivalent Design Waves (EDW)

4.2.1 EDW definition

Loads are induced by means of equivalent design waves. These waves are derived as explained in Rules.

Strength analysis is to be carried out considering the load cases described in [4.2.2] combined with wave parameter and heading as defined in Rules.

The target loads correspond to a return period of 25 years (probability level approximately of 10^{-8}).

4.2.2 EDW targeted effect

Load cases are defined by their targeted effects. The targeted effects are defined in the second column of Tab 7.

For the specific case of racking, the targeted effects are defined in Tab 8.

Table 8 : EDW targeted effect for racking case

Load case	Dominant Load Effect	Targeted load
Rack +	Racking	Positive transverse acceleration amidships at upper deck
Rack –	Racking	Negative transverse acceleration amidships at upper deck

5 Strength assessment

5.1 Yield strength assessment

5.1.1 General

The Von Mises stress calculation and yield criteria are defined in NR467, Pt B, Ch 8, App 3, [5].

5.2 Buckling assessment

5.2.1 General

All the structural elements in FE analysis carried out in accordance with this Section are to be assessed individually against the buckling requirements as defined in Ch 9, Sec 1.

6 Bending efficiencies

6.1 General

6.1.1 This paragraph aims at giving guidance for finite element calculations performed on a complete ship model in order to define bending efficiencies as described in Sec 3, [3.2].

Load case to be used is described in [6.2].

Method for stress reading is described in [6.3].

6.2 Load case

6.2.1 Bending efficiencies should be assessed with load case 1.1 as defined in Tab 7 (maximum positive vertical bending moment in hogging).

6.3 Stress reading

6.3.1 Bending efficiencies should be assessed with longitudinal stresses σ_x only where X is the ship longitudinal axis.

Appendix 2 Finite Element Analysis of Structural Details

1 General

1.1 Objective and scope

1.1.1 Application

This Appendix aims at providing guidance for detailed finite element calculation when this calculation is requested by the Society or it is proposed. A list of typical details is given in [1.3].

1.1.2 Type of analysis

This appendix aims at providing guidance for stress calculation for yielding and fatigue analysis on local models of structural details.

1.2 Strength analysis procedure

1.2.1 Procedure description

The following procedure applies to the yielding analysis of structural details:

- details modeled according to Article [2]
- loads and boundary conditions applied as defined in Article [3]
- strength assessment according Article [4]
- the procedure for fatigue analysis of structural details is described in Article [5].

1.3 List of details

1.3.1 Typical details

A fine mesh analysis should be performed for the following details:

- bulkhead door openings
- engine room casing
- large openings in upper decks
- large openings in longitudinal bulkheads
- atriums
- openings in webs of longitudinal girders and in webs of transverse deck beams and girders
- corners of shell doors openings
- corners of window openings
- ends of the side decks strips of the uppermost continuous deck
- transverse bulkhead openings.

1.3.2 Other details

Other location with high structural discontinuity may also be studied.

2 Structural model

2.1 Hot spot approach

2.1.1 Detail models may be either separate top-down models or hotspot models integrated in the complete ship model.

2.2 Extent of the model

2.2.1 The extent of the model should be sufficient so that the local effects of boundary conditions may be considered negligible on the assessment area.

In case of top-down separate model, the boundary nodes should correspond to nodes of the global model.

2.3 Finite element type

2.3.1 Plating should be modeled by shell elements.

Web and face plates of primary members should be modeled by shell elements.

2.3.2 Generally pillars and ordinary stiffeners may be modeled with bar elements.

On a case by case basis, pillars and ordinary stiffeners may be modeled by shell elements when their shape is to be accurately considered.

2.4 Structural modelling

2.4.1 Mesh size

Mesh size should not be greater than 50 x 50 mm.

Additionally, the mesh size should allow a correct description of the structure and a good representation of stress flow.

2.4.2 Mesh size around circular openings

Around circular, elliptic or ovoid openings, the fine mesh size should not be greater than 0,2 times the local radius of the edge.

2.4.3 Aspect ratio

The aspect ratio of elements is to be kept as close to 1 as possible and should not exceed 3. The use of triangular elements should be avoided.

2.4.4 Localized hot spots

For very localized hot spots, the model may have a variation of mesh density with a fine mesh area at hotspot localization. The fine mesh area should be in accordance with [2.4.1], [2.4.2] and [2.4.3]. Outside, the mesh may be greater, provided that a smooth transition is applied between outside and inside the fine mesh area.

3 Loads and boundary conditions

3.1 General

3.1.1 Loads and boundary conditions applied to the local models should be consistent with the calculations performed on the global ship model as described in App 1. Therefore loads and boundary conditions should be applied in accordance with the following:

- when the complete ship analysis was a Rule-load-based analysis, loads and boundary conditions defined in [3.2]
- when the complete ship analysis was a direct-hydrodynamic-load-based analysis, loads and boundary conditions defined in [3.3].

3.2 Loads and boundary conditions following a Rule-load-based complete ship analysis

3.2.1 Procedure

When a Rule-load-based complete ship analysis has been performed, forced displacement at boundaries defined in [3.2.3] and local loads defined in [3.2.4] should be applied for the load cases defined in [3.2.2]. Superimposition method is then to be applied to derive the corresponding stress level.

3.2.2 Load cases

The load cases to be applied to each type of details are defined in Tab 1, based on the load cases associated in App 1, Tab 7.

3.2.3 Forced displacement at boundaries

For each load case the resulting displacements of the complete ship model should be applied as nodal forced displacement at the boundaries of the local model.

3.2.4 Local loads

For each local load case, the deck loads, sea pressures or the global acceleration defined in App 1 should be applied to the local model.

3.2.5 Superimposition methodology

Stress components defined in App 1 should be obtained on the local model using the methodology defined in App 1 for the load cases combinations defined in App 1.

3.3 Loads and boundary conditions following a direct-hydrodynamic-load-based complete ship analysis

3.3.1 Approach

When a direct-hydrodynamic-load-based complete ship has been performed, the forced displacement at boundaries defined in [3.3.2] and pressures and accelerations defined in [3.3.3] should be applied to the local model.

3.3.2 Forced displacement at boundaries

For each direct load case, the resulting displacements of the complete ship model should be applied as nodal forced displacement at the boundaries of the local model.

Table 1 : Yielding load cases for details

Load case	Targeted effect	Details in horizontal longitudinal elements	Details in transverse structural elements	Details in vertical longitudinal elements	Openings in webs of longitudinal girders and in web of transverse deck beams and girder
1.1	Maximum positive vertical bending moment (hogging)	X	–	X	–
2.1	Maximum negative vertical bending moment (sagging)	X	–	X	–
1.2	Maximum positive vertical bending moment (hogging)	–	–	X	–
2.2	Maximum negative vertical bending moment (sagging)	–	–	X	–
3	Maximum positive vertical shear force in the midship area	–	–	X **(1)**	–
4	Maximum negative vertical shear force in the midship area	–	–	X **(1)**	–
5	Maximum negative vertical acceleration	–	–	–	X
7.1	Maximum horizontal bending moment	X	–	X	–
7.2	Maximum horizontal bending moment	–	–	X	–
8	Maximum transverse acceleration (racking)	–	X	–	–
(1) If the detail is located in midship area.					

3.3.3 Ship pressures and accelerations

If deemed relevant on a given load case, accelerations and pressures resulting from the complete ship analysis should be applied to the local model.

4 Strength assessment

4.1 Stress reading

4.1.1 Stress components in shell elements

The Von Mises equivalent stress, σ_{VM}, in N/mm², is to be derived as follows:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2 + 3\tau_{12}^2}$$

Where σ_1, σ_2 and τ_{12} are defined in Sec 2, [3.5.2].

4.2 Yielding assessment

4.2.1 Criterion

Both following criteria should be checked:

- the average Von Mises equivalent stress $\sigma_{VM\text{-}av}$ as per Rules
- the equivalent stress σ_{VM} as per Rules.

4.2.2 Stress averaging

The average Von Mises equivalent stress $\sigma_{VM\text{-}av}$, in N/mm², is to be obtained from the procedure defined in the Rules.

where:

for fine mesh along rounded edges (openings, rounded brackets) the area considered for stress averaging is to be limited only to the first ring of border elements, over a length not greater than 1,5 times the local radius of the edge.

Appendix 3 Vehicle Cargo Loading for Direct Hydrodynamic Load Based Analysis using a Complete Ship Model

1 General

1.1 Application

1.1.1 This Appendix describes the method to model vehicle cargo on decks in case of a direct hydrodynamic load based analysis.

1.2 Principle

1.2.1 General

The general idea is to model uniform distribution of loads on each deck and not the local tyre print loads.

For each plate element i, a mass element is created and linked to all nodes of the plate element. The value of mass, the position of mass, and the weight per nodes for the link of mass to plate are defined in Article [2].

1.2.2 Constraints

Specific attention should be given to the following items when creating and positioning these mass elements:

- correct distribution of mass of cargo per deck (affect inertia)
- loaded zones on the deck
- vertical location of center of gravity of vehicles with respect to deck level
- global position of center of gravity of the loaded ship.

2 Modeling

2.1 Mass elements

2.1.1 A possible way is to add for each plate element i of a loaded zone of the deck, a mass element linked by rigid interpolation elements to the nodes of the plate elements.

The distribution of mass M_t should respect the constraints described in [1.2].

If the center of gravity of the vehicles loaded on the considered zone of deck is located at the geometrical center of the area, the elementary masses may be taken as follows:

$$M_i = \frac{A_i}{A_t} C_{F,i} M_t$$

where:

A_i : Projected area of element under consideration

A_t : Total surface area of the elements of loaded part of the deck:

$A_t = \Sigma_i A_i$

M_t : Total mass of vehicles on the deck

$C_{F,i}$:
- If the center of gravity is centered above the loaded part of the deck:

  $C_{F,i} = 1$
- If not:

$$C_{F,i} = \left(1 + \varepsilon_x \frac{x_i}{L_{Dx}}\right)\left(1 + \varepsilon_y \frac{y_i}{L_{Dy}}\right)$$

where:

$$\varepsilon_x = \frac{3L_{Dx} - 3d_x}{L_{Dx} + 3d_x}$$

$$\varepsilon_y = \frac{3L_{Dy} - 3d_y}{L_{Dy} + 3d_y}$$

x_i, y_i, d_x, d_y, L_{Dx}, L_{Dy}: parameters defined in Fig 1.

2.1.2 Position

The vertical position of the mass element is to be defined so that the center of gravity of the complete ship model matches the one of the considered loading condition.

The longitudinal and transversal location of the mass elements with respect to plate element geometry should be positioned above the geometrical center of projected surface of the element.

2.2 Rigid interpolation elements

2.2.1 Position

A rigid interpolation element is to be created for each plate element. The master nodes should be the nodes of the plate elements. The dependent node should be the node of the corresponding mass element.

2.2.2 Weighing coefficient for each nodes

The load transmitted to each node j of the element i should be appropriately set with the use of different coefficients for each node based on element geometry and area:

$$W_j = \frac{A_j}{A_i}$$

where:

A_j : The area associated to node j as per Fig 2.

Figure 1 : Relative position of element i on the loaded part of deck

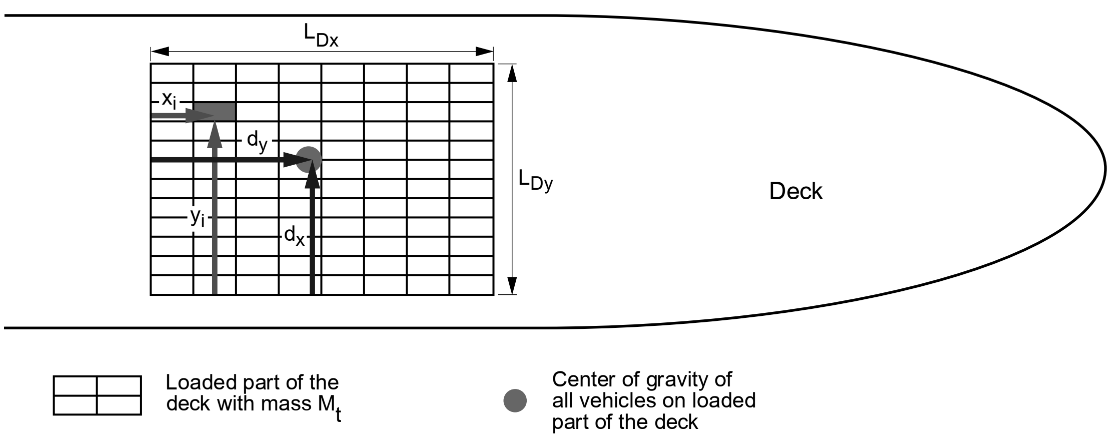
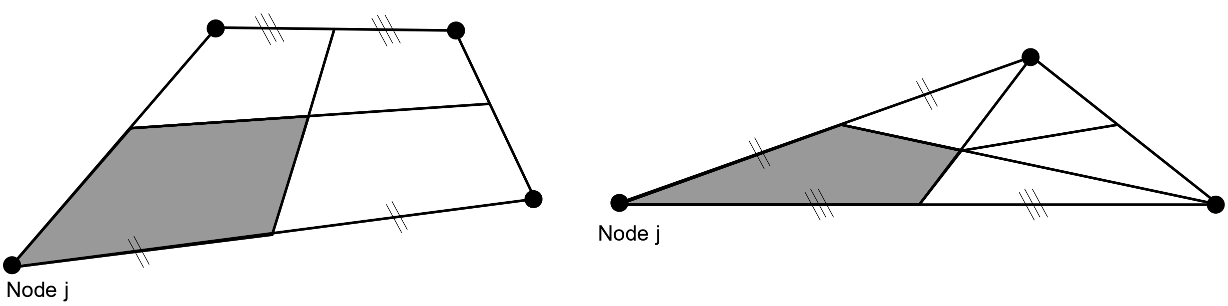


Figure 2 : Calculation of area A_j



Appendix 4 Racking based on 3D beam model

1 Racking calculation

1.1 Introduction

1.1.1 Racking is a global phenomenon of the ship structure. A global ship model is therefore to be used in order to assess this behaviour. The global model may either be a 3D beam model or a FE model.

Local models are also used for the assessment of structural details.

Calculation principles for 3D beam model are described in [1.2].

Calculation principle for FE model are described in App 1.

1.2 3D beam model calculation principles

1.2.1 The following steps are to be followed when using a 3D beam model:

a) Create global model of the relevant structure:
   - Longitudinally, the model is to extend from the aftermost to the foremost transverse bulkheads efficiently restraining the transverse displacement. If such bulkheads are not fitted, the longitudinal extent of the model is not to be limited.

     Vertically, the model is to extend from the lowermost to the uppermost deck where transverse web frames can be considered efficiently clamped (typically in way of freeboard deck where transverse watertight bulkheads end). In way of vertical web frames where such transverse elements are not fitted, the model is to be extended to the deck below.
   - The primary vertical shell structure and transverse deck structure are to be modelled. Similar web frames can be combined into a single beam in order to simplify the model.
   - The deck stiffness is to be modelled using a beam at the center line representing the deck with attached shell plating as flanges. Attention is to be paid to areas including deck openings.

b) Apply the following boundary conditions:
   - All shell and internal nodes connected to transverse bulkheads and decks efficiently restraining the transverse displacement and rotation around the ship longitudinal axis are to be fixed in x-, y- and z- directions and Rx, Ry and Rz rotations (typically all nodes connected to transverse bulkheads in way of freeboard deck).
   - All shell and internal nodes connected to decks only restraining transverse displacement are to be simply supported in x-, y- and z-directions.
   - In way of longitudinal ends of the model and if connected to transverse bulkheads sufficiently restraining the transverse displacements, deck nodes are to be simply supported in -x, -y and -z directions. If relevant, the rotation around z-axis may also be fixed.

c) Load the model:
   - Still water loads: wheel loads, accommodation loads, cargo loads (no sea pressure, no wind pressure) and steel weight.

     If no data has been submitted by the designer the following values might be considered as guidance:
     - steel weight based on the scantlings indicated on the relevant drawings
     - 170kg/m^2 for outfitting
     - 75 kg/person (amount of people/deck distributed evenly on each deck)
     - cargo weight defined on midship drawing in case no loading manual is available.
   - Transverse inertial loads (based on the transverse acceleration in the midship area): inertial wheel loads, inertial accommodation and steel weight loads.

d) Compute the resulting deformation.

e) Create a top-down model of the area where strength is intended to be investigated.

f) Apply the following boundary conditions:

   In addition to those defined in b):
   - forced displacement in y-direction is to be applied to all deck nodes in accordance with the results from the global model for the concerned locations
   - additional degrees of freedom may be considered fixed depending on the actual structural arrangement.

g) Load the local model with the relevant loads:
   - rule vertical loads for load case BR1 (static + dynamic)
   - rule sea loads on side shell for load case BR1.

h) Compute the resulting stresses.

2 Structural elements to be reviewed

2.1 General

2.1.1 Structural elements to be checked against racking are:

- for yielding:
  - transverse elements subject to transverse loads (side shell frames, central casing frames and transverse bulkheads)
  - connection between beams and vertical web frames (see also Sec 3, [6.5])
- for buckling:
  - decks
  - side shell and central casing plating.

Other locations might be critical depending on the design.

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