CLASSIFICATION NOTES

No. 31.7

STRENGTH ANALYSIS OF HULL STRUCTURES IN CONTAINER SHIPS

OCTOBER 2009

DET NORSKE VERITAS

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FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

Classification Notes

Classification Notes are publications that give practical information on classification of ships and other objects. Examples of design solutions, calculation methods, specifications of test procedures, as well as acceptable repair methods for some components are given as interpretations of the more general rule requirements.

A list of Classification Notes is found in the latest edition of Pt.0 Ch.1 of the “Rules for Classification of Ships” and the “Rules for Classification of High Speed, Light Craft and Naval Surface Craft”.

The list of Classification Notes is also included in the current “Classification Services – Publications” issued by the Society, which is available on request. All publications may be ordered from the Society’s Web site http://webshop.dnv.com/global/.

The Society reserves the exclusive right to interpret, decide equivalence or make exemptions to this Classification Note.

Amendments and Corrections

This document is valid until superseded by a new revision or withdrawn. Minor amendments and corrections will be published in a separate document normally updated twice per year (April and October).

For a complete listing of the changes, see the “Amendments and Corrections” document located at:
http://webshop.dnv.com/global/, under category “Guidelines and Classification Notes”.

The electronic web-versions of the DNV Classification Notes will be regularly updated to include these amendments and corrections.

Main changes

This document replaces the May 2004 edition.

The modifications are related to:

— updates due to rule revisions
— following changes in the industry - new items added
— revisions and clarifications of text
— minor editorial changes.

Incorporating:

— calculation procedures
— load definitions
— allowable stresses
— general revisions.

Comments may be sent by e-mail to *rules@dnv.com*
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1. Introduction

1.1 General

The DNV Rules for Classification of Ships may require direct structural strength analyses in case of a complex structural arrangement, or unusual vessel size.

This Classification Note describes the scope and methods required for structural analysis of container ships and also the background for how such analyses should be carried out. The description has been based on relevant Rules for Classification of Ships, guidance and software.

1.1.1

Structural analysis carried out in accordance with the procedure outlined in this Classification Note will normally be accepted as basis for plan approval.

1.1.2

Where in the text it is referred to the Rules for Classification of Ships, the references refer to the latest edition of the Rules for Classification of Ships.

1.1.3

Any recognised calculation method or computer program may be utilised provided the effects of bending, shear, axial and torsion deformations are considered when relevant.

1.1.4

If the wave loads are calculated from a hydrodynamic analysis, it is required to use recognised software. As recognised software is considered all wave load programs that can show results to the satisfaction of the Society.

1.2 Objectives

The objective of this Classification Note is:

- To give a guidance for design and assessment of the hull structures of the 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.

1.3 Container ship categories

1.3.1

Container ships are ships designed exclusively for the transportation of container cargoes. Containers are standardised in several sizes, e.g. 20 ft, 40 ft, 45 ft and 48 ft long containers are common. The most common size is 20 ft (TEU: Twenty feet Equivalent Unit) and 40 ft (FEU: Forty feet Equivalent Unit) long containers. The size of the container ship will be influenced by the characteristics of the route and trade pattern for which the ship is employed. The ships may be categorised as follows according to the size group:

Feeder Container ship: A container ship which can carry 100 TEU- 2 000 TEU and is mainly employed for short voyages between hub ports and small ports in the vicinity. Normally the ships are equipped with cranes for speedy loading and unloading.

Sub-panamax: A container ship which can carry 2000 TEU – 3000 TEU on board and is mainly used as a feeder container ships. Loading flexibility and speed are two of the main requirements for these ships.

Panamax: A container ship which can carry up to about 4800 TEU on board. Main dimensions are designed for the passage through the Panama Canal. Most of these ships were designed for the inter-continental trade routes, e.g. Asia-Europe, Asia-USA and Europe-USA. Some of them are still employed on these routes. However, the traditional panamax fleet is gradually being replaced by Post-panamax container ships on these trade routes.

Torsion is often a major concern of the panamax due to its high length to beam ratio. Some ships are designed with lashing bridges and there are normally 8-9 container tiers in hold stowage.

Post-panamax: A container ship which cannot pass the Panama canal due to the wide beam and/or longer length. Modern post panamax container ships typically have a capacity of 5 500 TEU to 9 000 TEU. Due to economy of scale, the popular size tends to increase continuously. Current large designs under construction have a capacity up to about 13 000 TEU. Container ships of this size are also called Ultra Large Container Ships. ULCS designs with capacity of 16 000 TEU are under discussion.

It is expected that the trend will continue until new container ship reaches the size ceiling established by market demand and available technology.

1.3.2

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 Note focuses on typical loading conditions and load cases 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 ship yards 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.

1.4 Definition of symbols and abbreviations

Symbols not mentioned in the following list are given in connection with relevant formulae. The general symbols may be repeated when additional definitions are found necessary in connection with specific formulae.

L = Rule length in m 1)
B = Rule breadth in m 1)
D = Rule depth in m 1)
T = Rule draught in m 1)
T_A = draught in m for considered condition
T_B = draught in m for ballast condition
C_B = Rule block coefficient 1)
C_W = wave coefficient 2)
V = maximum service speed in knots on draught T
E = modulus of elasticity, $2.1 \cdot 10^5$ N/mm^2 for steel
G = shear modulus, $0.7 \cdot 10^5$ N/mm^2 for steel
a_v = combined dynamic vertical acceleration in m/s^2 2)
g_o = standard acceleration of gravity, 9.81 m/s^2
h_{db} = height of double bottom in m
ϕ = rolling angle 2)
θ = pitching angle 2)
ULS = Ultimate Limit State (i.e stress, yield and buckling check)
FLS = Fatigue Limit State.

1) For details, see the Rules for Classification of Ships Pt.3 Ch.1 Sec.1.
2) For details, see the Rules For Classification of Ships Pt.3 Ch.1 Sec.4 B.

2. Scope of Analysis

2.1 General

In order to achieve above objectives, the following procedure and tools may be used depending upon the characteristics of the vessel and the required analysis scope:

- Local Rule scantling for typical midship section and other necessary cross sections using NAUTICUS Hull[1] Section Scantlings
- Rule torsion calculation using NAUTICUS Hull Section Scantlings, 3-D BEAM and DNV Simplified Torsion Calculation Tool
- Cargo hold analysis for the assessment of primary structures in the midship area using NAUTICUS Hull FE modelling and analysis tools
- Global analysis modelling the complete ship length and using load cases obtained either by direct wave load analysis or Rule defined loads
- Wave load analysis[2] as part of a global analysis using WASIM[3] or equivalent
- Hatch corner analysis with fine mesh model for selected hatch corner locations
- Fatigue assessment for the selected hatch corners and the typical longitudinal connections in way of side shell and bilge area.

1) "NAUTICUS Hull" is a computer program, offered by DNV, that is suitable for the calculations of Rules required scantlings and cargo hold analysis, etc.

2) Direct wave load analysis is not part of the mandatory requirement for NAUTICUS (Newbuilding) class notation, and is therefore to be carried out at owner's and/or builder's discretion. However for extraordinary vessel design, such comprehensive analysis scope including wave load/global analysis is recommended.

3) WASIM is a linear/non-linear time domain computational tool for seakeeping and load analysis of ships. The complete 3D interaction between waves and hull at forward speed is included. The computer program is not limited to small waves but can simulate also extreme wave conditions.

2.2 Overview of different analysis levels

In order to achieve the above objectives, four different analysis levels are defined.

The four different analysis levels are applicable for the design of container ships according to the vessel characteristics as described in Table 2-1.

Level 1 analysis shall normally be carried out as part of the mandatory procedure for the NAUTICUS(Newbuilding) notation. However, strengthening required by the Level 1 analysis may be overruled by findings from further comprehensive analysis according to Level 2, Level 3 and Level 4.

Level 2 analysis includes a Level 1 analysis in total. Similarly, Level 3 analysis includes Level 2 analysis and so forth.

Table 2-1 Analysis levels versus calculation/analysis scope

Level	*Rule Calculation (Level 1 Analysis)*	*Extended Rule Calculation (Level 2 Analysis)*	*Moderate Direct Strength Assessment (Level 3 Analysis)*	*Comprehensive Direct Strength Assessment (Level 4 Analysis)*
Applicable Notation	NAUTICUS (Newbuilding)*	NAUTICUS (Newbuilding)	NAUTICUS (Newbuilding)	CSA-(2) Equivalent
Mandatory scope of calculation /analysis	— Hull girder strength calculation for vertical bending moments (Rules for Classification of Ships Pt.5 Ch.2 Sec.6 B200) — Cargo hold analysis based on Rule defined loading conditions ** — Rule fatigue strength calculation for longitudinal connections ** — Rule torsion calculation (ULS) for longitudinal members and hatch corners (Rules for Classification of Ships Pt.5 Ch.2 Sec.6 B204) — Rule torsion calculation (FLS) for hatch corners (Rules for Classification of Ships Pt.5 Ch.2 Sec.6 C309)			
Supplementary scope of Analysis	-	Global FE Analysis with Rule torsion load cases (ULS)	Direct wave load analysis for ULS	Direct wave load analysis for ULS and FLS analysis
	-	-	Global FE Analysis with loads according to the Rules for Classification of Ships and according to direct wave load analysis (ULS)	Global FE analysis with direct calculated wave loads (ULS and FLS)
	-	-	Hatch corner fine mesh FE analysis (ULS)	Hatch corner fine mesh FE analysis using (ULS and FLS)
	-	-	-	Cargo Hold analysis for additional dynamic load cases
Remarks	Suitable for small ships less than panamax and with normal design	Required for large ships from panamax size. However, for designs with experience either from DNV or designs, a Level 1 analysis may be sufficient.	Recommended for Extraordinary Design	Recommended for Extraordinary Design
* NAUTICUS(Newbuilding) notation is mandatory for Container Carriers of length greater than 190 m. ** For designs where the NAUTICUS(Newbuilding) notation is mandatory, the structural verification procedure require the use of FEA in the evaluation of the midship cargo hold region. In addition, extended fatigue evaluations of end structures of longitudinals within the cargo region are required (Rules for Classification of Ships Pt.5 Ch.2 Sec.6 C309).				

2.3 Level 1 analysis

2.3.1 General

The Level 1 analysis is in line with standard Rule scope.

2.3.2 Application

This procedure is mandatory for all container ships irrespective of the ship size. For ships up to about panamax size, a Level 1 analysis may be sufficient for the strength assessment. A Level 1 analysis may also be sufficient for post-panamax design where either DNV or the designer can document previous experience.

2.3.3 Local scantlings

Local scantlings for all relevant structural members in the sections can be checked against relevant Rule requirements using

Nauticus Hull Section Scantlings or equivalent, following the procedure described in section 4.

2.3.4 Longitudinal strength and torsion analysis

Longitudinal strength of the vessel including torsion response can be verified by the Rule defined calculation procedure as described in section 6. Nauticus 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 needs to be specially considered. The actual design bending moment should be applied at each section. By design bending moment is meant the design still water bending moment according to section 4.1 plus the wave bending moment according to the Rules for Classification of Ships.

The torsion analysis should be according to the procedure described in section 6.

Allowable stresses are given in section 12. Stress concentration factors for the hatch corner analysis are found in section 14.

2.3.5 Fatigue assessment

With the application of the **NAUTICUS(Newbuilding)** notation, the fatigue characteristics of end structures of longitudinals in bottom, inner bottom, side, inner side/longitudinal bulkheads and decks should be assessed

For other designs, as a minimum the fatigue characteristics of side shell longitudinal connections should be evaluated.

Fatigue assessment tool for both levels are integrated in the NAUTICUS Hull Section Scantlings software package. Calculation procedures are further described in section 15.

Separate fatigue calculations shall be carried out for the hatch corners following the procedure described in section 15 and with stress concentration factors according to section 14.

2.3.6 Cargo Hold Analysis

Strength of the typical primary structural members in the midship area is to be assessed through a cargo hold analysis using Nauticus Hull FE modelling and analysis tools or equivalent. The complete analysis including modelling, load cases, strength assessment, allowable stresses and buckling control should be carried out according to the procedures described in section 5.

For fuel oil deep tanks arranged in the cargo area, i.e. fuel oil deep tanks located inboard of the inner side, above the inner bottom, and between adjacent transverse bulkheads, additional strength analysis should be carried out in order to determine the required scantling of primary structure. Applicable procedures are described in Appendix E.

2.4 Level 2 analysis

2.4.1 General

The Level 2 analysis covers all analysis scope of Level 1 (see section 1.1).

The main objective of this analysis is to ensure that the global structural response complies with the Rule defined acceptance criteria using a simplified global torsion analysis method.

The analysis includes a global structural model covering the entire ship length. The analysis is carried out against torsion combined with other simultaneous hull girder load components according to the Rules for Classification of Ships.

The Rule defined hull girder loads will be applied to the global structural model as vertical and horizontal forces over the ship length.

The deformations obtained at the hatch coaming top will be used as a guidance to the hatch cover manufacturer for the design of hatch cover supports and stoppers.

2.4.2 Application

This procedure is mainly aimed at a full Panamax size (panamax long length) and Post-Panamax container ships but may also be suitable even for small sized ships having particular structural arrangement.

2.4.3 Objectives

— To examine hull structural response to torsion moment combined with vertical bending moments and horizontal bending moments
— To obtain hull deflections at the hatch coaming top and the upper deck levels
— To assess the hull girder strength also outside the midship area.

2.4.4 Longitudinal strength and torsion analysis

A simplified global FE analysis is to be carried out. The FE model should be according to the procedure described in section 7.

The loads on the model should be according to the Rules for Classification of Ships and the load application should be according to the procedure described in section 8.

The stress combination should be according to section 11.

The longitudinal stresses obtained by the global analysis shall be checked for nominal stress at the hatch coaming top, at the intersection of upper deck and longitudinal bulkhead and the bilge plating over the entire hull.

The stresses at the transverse box beam structures in fore and aft cargo hold regions shall also be checked for the torsion load cases.

The peak stresses in way of the hatch corners may be calculated by multiplying the nominal stresses obtained from the global analysis model with the stress concentration factors found in section 14.

Allowable stresses for yield and buckling should be according to section 12.

2.4.5 Hatch coaming deformations

The deformations obtained at hatch coaming top level will be used as a guidance to the hatch cover manufacturer for their design of hatch cover supports and stoppers.

2.5 Level 3 analysis

2.5.1 General

In addition to the scope of the Level 2 analysis, the Level 3 analysis also includes a direct wave load analysis where the loads are applied to the global FE model in a simplistic manner.

The Level 3 analysis can be adopted as an option for the shipyard or the ship owner, and is not mandatory for the **Nauticus(Newbuilding)** notation.

2.5.2 Application

This analysis level is recommended for container ships having extraordinary structural arrangement or main dimensions as well as ships of novel design.

2.5.3 Objectives

The objective of the Level 3 analysis is to examine the hull girder strength against more realistic wave loads and to investigate the structural response to a broader selection of load cases.

2.5.4 Wave load analysis

Wave load analysis using WASIM or equivalent shall be carried out to give extreme direct hull girder forces in relevant sea states (ULS). Non-linear wave load effect should be taken into account in the analysis.

The design still water bending moments (hogging and sagging) are to be combined with the corresponding relevant extreme wave bending moment.

The wave load should be calculated according to the procedures described in section 10.

All hull girder forces will be applied to the FE model as concentrated forces or equivalent along the length of the ship, following the procedure as described in section 8.

2.5.5 Longitudinal strength and torsion analysis

The calculation procedure for longitudinal strength and torsion response are similar to the Level 2 analysis. However, the structural response should be analysed for both the Rule loads and the above direct calculated wave loads.

The load cases to be analysed are described in section 11.2 for the Rule loads and in section 11.3 for the direct calculated wave loads.

The allowable stress should be according to section 12.2.

2.5.6 Hatch coaming deformation

The deformations obtained at hatch coaming top level will be used as a guidance to the hatch cover manufacturer for their design of hatch cover supports and stoppers.

2.6 Level 4 analysis

2.6.1 General

The Level 4 analysis involves the most comprehensive analysis scope. The scope is comparable to that required for the CSA-2 class notation according to the Rules for Classification of Ships Pt.3 Ch.1 Sec.15 E.

2.6.2 Application

This analysis will be adopted as an option by the shipyard or ship owner and is not mandatory for the **NAUTICUS(Newbuilding)** notation. This analysis is recommended for container ships having extraordinary structural arrangement or main dimensions as well as vessels of novel design.

2.6.3 Objectives

The objectives of this analysis level is:

- To calculate the design wave for maximum vertical wave bending moment in up-right condition and for maximum stress combined by wave torsion, horizontal and vertical bending moment in oblique waves
- To examine hull structural response against the chosen maximum conditions, as above with regard to buckling and yield.
- To obtain hull deformations at hatch coaming top level
- To assess the strength of the fore and aft body.

2.6.4 Wave load analysis

A direct wave load analysis should be carried out in a similar manner as for the Level 3 analysis following the procedure described in section 10.

The wave load analysis should be carried out in extreme sea conditions (ULS) to calculate hull girder forces and moment. Additionally, loads used for fatigue analysis (FLS) should be established following the procedures in section 10.

The loads (external pressure and inertia loads) should be applied to the global structural model following the procedures described in section 10.

The FE model needs to include the masses. The reason for this is that the inertia forces should be included in the model to counteract the external sea pressure. The procedure for modelling the masses is described in section 9.

2.6.5 Longitudinal strength and torsion analysis

The calculation procedure for longitudinal strength and torsion response is similar to the Level 3 analysis. However, the structural response should be analysed based on direct wave load calculation.

The load cases to be analysed are described in section 10.8.

Peak stresses in the hatch corners should be studied making a fine mesh model according to the recommendation in section 13.

The allowable stress for the peak stress in hatch corners should be according to section 12.3.1.

Yield and buckling strength assessment will be carried out by using the acceptance criteria in section 12.3.

2.6.6 Strength assessment

In general, hatch coaming top, upper deck, bottom and bilge areas are the major critical areas for examination of stresses.

For the structures with high compressive stress, buckling strength is to be checked.

2.6.7 Fatigue analysis

A comprehensive fatigue analysis is to be carried out for critical locations. Three hatch corners, i.e. one amidships and one at the each end of the cargo hold area, are normally to be analysed.

The local FE models should be made according to the description in section 13.

The fatigue assessment should be carried out following the procedure described in section 16.

2.6.8 Deformation

The deformation of the hatch coaming in the torsion load case is important for the hatch cover design.

The deformation shall also be considered in connection with lashing, e.g. lashing bridge may take additional force due to relative movement between hatch cover and hatch coamings.

The deformation in hatch diagonals may be observed in the initial phase for comparison purpose.

3. Design Loads

3.1 Definition of units

The following SI-units are used in this Classification Note:

Description	*Unit*	*Symbol*
Mass	tons	[t]
Length	millimetre NOTE: metre [m] is used in some cases as stated in each case	[mm]
Time	second	[s]
Force	kilo Newton Newton [N] is used in some cases as stated in each case	[kN]

3.2 Design loads

Design pressure loads due to external sea pressure, liquids in tanks and due to cargo, except as given in sections 3.3 and 3.4, are to be taken as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.12 B302 – 305.

3.3 Container forces

3.3.1 Upright condition

The vertical force of a container or stack is not to be taken less than:

P_V = $(g_o + 0.5a_v)$ M [kN]
a_v = Dynamic vertical acceleration according to the Rules for Classification of Ships Pt.3 Ch.1 Sec.4 B601
M = mass of container or container stack (tons)

3.3.2 Heeled condition

The vertical force of a container or stack is not to be taken less than:

$P_V = g_o M$ [kN]

3.3.2.1

The transverse force of a container or a stack is not to be taken less than:

$P_t = 0.5\ M\ a_t$ [kN]
a_t = dynamic transverse acceleration
= $0.4a_y + g_o \sin\phi + a_{ry}$ [m/s^2]

a_y and a_{ry} are as given in the Rules for Classification of Ships, Pt.3 Ch.1 Sec.4 with R_R taken with a negative sign for positions below the centre of rolling. For loading conditions with maximum cargo load on the upper decks, the transverse dynamic acceleration a_t, may be based on the GM value from the loading manual and not on the standard values given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.4 B400.

The GM-value is not to be taken less than:

— 0.05B with B < 32.2 m
— 0.08B with B > 40.0 m
For intermediate values, linear interpolation should be used.

The transverse force P_t is a dynamic load at probability level 10^{-4}, and the results may be used for simplified fatigue control.

3.3.3 Pitching condition

The vertical force of container/stack is not to be taken less than:

$P_v = g_o M$ [kN]

The longitudinal force of a container or stack is not to be taken less than:

$P_t = 0.5\ M\ a_l$ [kN]
a_l = dynamic longitudinal acceleration
= $0.6a_x + g_o \sin\theta + a_{px}$ [m/s^2]

a_x and a_{px} are as given in the Rules for Classification of Ships, Pt.3 Ch.1 Sec.4 with R_P taken with a negative sign for positions below the centre of pitching. The centre is generally not to be taken at a higher level than the considered draught.

3.4 Sea pressure load

3.4.1 Upright Condition

The sea pressure in upright condition is to be taken as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.12 B300.

3.4.2 Heeled condition

The external sea pressures p, in heeled conditions is normally to be taken as:

$p = 10\ (T_A - z) + 10\ y \tan(\phi/2)$ [kN/m^2]

on submerged side and

$= 10\ (T_A - z) - 10\ y \tan(\phi/2)$ [kN/m^2]

on emerged side

= 0 minimum.

T_A = actual considered draught in m
z = vertical distance in m from base line to considered position
y = transverse distance in m from centre line to considered position
ϕ = as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.4 B.

For external sea pressure to be applied for strength analysis of fuel oil deep tank structure in container hold, please refer to Appendix E.

4. Longitudinal Strength and Local Rule Scantlings

4.1 Limits for still water bending moment

— In general, the design still water bending moment amidships is to be taken as the greater of:
  — maximum value according to the loading conditions in “Trim and Stability Booklet” + margin[1)]
  — rule value as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.5 B106 + margin[1)]

  The Design still water bending moment may however, subject to acceptance in each case, be based on the envelope curve representing all relevant fully and partly load cargo and ballast conditions as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.5 B101.
— For other sections along the ship length, the design still water bending moment curve should vary smoothly to fore and aft ends with a suitable margin over the maximum values of loading conditions.
— It is recommended to have 5% margin in general to the envelope over the maximum still water bending moment according to the “Trim and Stability Booklet”.
— The longitudinal distributions of the vertical wave bending moment, horizontal wave bending moment and torsion wave moment shall be according to the Rules for Classification of Ships.

Note:

The margin relative to the design bending moment is normally to be decided based on the agreement between the builder and the owner.

---e-n-d---of---N-o-t-e---

4.2 Limits for still water shear force

The still water shear force limits (positive and negative) along the hull shall be established for a seagoing and a harbour condition. The still water shear force limits shall be establish by a shear flow analysis. The shear flow analysis shall be carried out at several longitudinal positions in order to establish a shear force limit curve that reflects the hull girder shear force capacity over the length of the ship.

The allowable shear force at any position along the hull length is determined as:

$$Q_{\max} = \frac{t \cdot \tau}{SF \cdot 9810} \quad \text{(tons)}$$

where

SF = shear flow [N/mm]
t = thickness [mm] at the position of calculated shear flow
τ = 110 f_1 or the shear buckling capacity (whichever is less)
f_1 = material factor (see Table 12-1).

As the shear flow will vary over the cross section, the lowest Q_{max} according to the above procedure shall be used as the shear force limit.

Shear force correction at the water tight bulkheads need not to be carried out in general.

4.3 Limits for still water torsion moment

The still water torsion limit along the hull girder can be assumed constant and equal to:

$M_{ST} = 0.3\ L\ B^2$ [kNm]

4.4 Scantling check positions

A local section scantlings analysis (i.e. all local Rule requirements) shall normally be calculated for the cross sections where the structural arrangement and the scantlings of longitudinal members are changed.

4.5 Calculation procedure

— The scantlings of all structural members amidships can be decided by Nauticus Hull Section Scantlings. A feasibility study for alternative structural arrangements and designs can also be done quickly.
— NAUTICUS Hull Section Scantlings will check the proposed scantlings against local Rule requirements as well as hull girder strength requirements. Bending, shear and buckling strength for plates and stiffeners are of major concern in Section Scantlings, but other local rule requirements such as connection and weld area can be assessed by the program.
— Simplified fatigue assessment of end connections of longitudinal stiffeners can be checked by Nauticus Hull Section Scantlings.
— Data for torsion response calculation can be obtained by Section Scantlings for the midship section. The deformations from this calculation will be used in a beam analysis (e.g. 3-D Beam calculation) combined with the DNV Simplified Torsion Calculation Tool to calculate the stress in upper deck structures due to warping deformation.

5. Cargo hold analysis

5.1 General

The objective of the cargo hold analysis is to determine the scantling of typical primary structural members such as girders, floors in double bottom, transverse webs, stringers in bulkhead structures in the midship area.

5.2 Model position

Normally, a cargo hold model is only carried out amidships.

However, additional calculation may also be carried out for the fore end and the aft end as the hull shape and structural arrangement is changed significantly compared to those in the midship region.

5.3 Analysis model

5.3.1 Model extent

The necessary longitudinal extent of the model will depend on structural arrangement applied boundary conditions and loading conditions.

The analysis model shall normally extend over two (2) hold lengths (1/2 hold + 1 hold + 1/2 hold, i.e. 4 × 40 ft container bays).

The model shall cover the full breadth of the ship in order to account for unsymmetrical load cases (heeled or unsymmetrical flooding conditions).

A half breadth model is acceptable in case of symmetric loading in the transverse direction. Symmetry boundary condition should then be applied at the centre line.

Even for the heeled condition a half breadth model may be accepted if due concern is shown to boundary conditions and their influence on the results.

The model shall represent the holds located around amidships.

In principle the actual shape of outer shell may be represented as it is. However, the simplification by using the shape of the midship section unchanged for the whole model length is also acceptable if due consideration is given to the stress evaluation of the changed structures.

In general, to avoid inaccuracies in results due to boundary condition effects, the structural evaluation should typically be based on results away from the model boundary conditions. For a normal model extent as described above, with loading conditions as described in section 5.5, the structural evaluation may typically be based on results for the middle hold.

The extent of the recommended model is visualised in Figure 5-1.

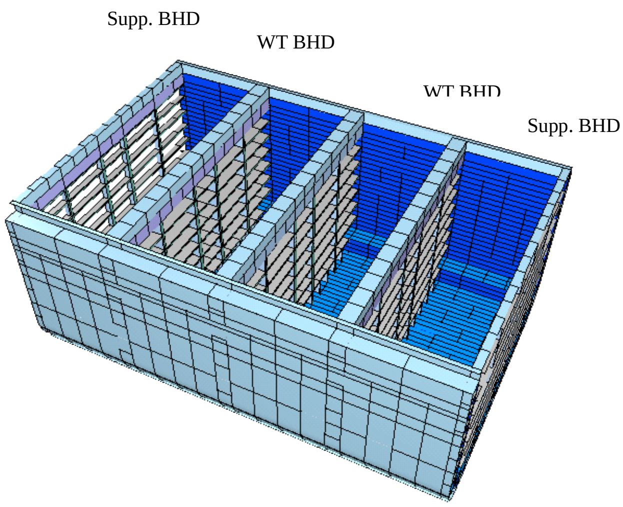

Figure 5-1
Model range of cargo hold analysis

5.3.2 Modelling of geometry

Decks, shell, inner bottom and longitudinal bulkhead plates shall be modelled with shell elements in order to take lateral loads.

Transverse webs, floors, girders and stringers may be of membrane elements.

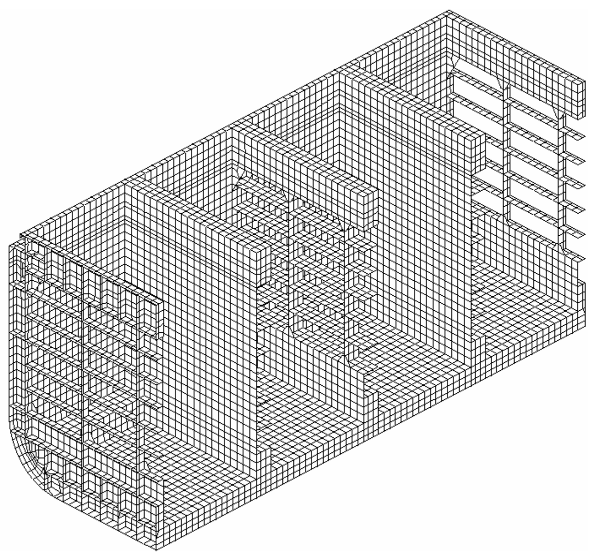

Figure 5-2
3-D view of cargo hold model

Face plates of primary structures, e.g. vertical webs and stringers of transverse bulkheads may be represented by either beam elements or truss elements.

All continuous longitudinals and stiffeners on shell elements shall be of beam element type in order to transfer the internal and external loads to the neighbouring primary structural members.

Non-continuous secondary structures such as web stiffeners on girders and floors may be included in the model by truss element when considered important, otherwise they may be ignored.

If non-continuous stiffeners are included in the model, then effective sectional area of such stiffeners may be calculated as follows:

Sniped at both ends	: 30% of actual area
Sniped at one end	: 70% of actual area
Connected at both ends	: 100% of actual area

Hatch coamings shall be included in the model but hatch covers can be excluded in the model.

The structure shall, according to the Rules for Classification of Ships, be modelled with net scantlings, i.e. corrosion addition shall be deducted from the actual scantlings.

Half thickness shall be applied on plates in symmetry plane at the boundaries of the model.

5.3.3 Element and mesh size

The stress and deformation results from the analysis are linked to the type-, shape- and aspect ratio of the elements, and mesh topology that are used. The following guidance on mesh size is based on 4-noded shell or membrane elements in combination with 2-noded beam or truss elements.

Higher order elements such as 8-noded or 6-noded elements with a coarser mesh than described below may be used provided the structure and the load distribution are properly described.

The element mesh should preferably represent the actual shape of the structures so that the stresses for the control of yield and buckling strength can be read and averaged from the results without interpolation or extrapolation. Some secondary stiffeners is therefore recommended to be modelled for mesh control.

The following is considered as guidance for the mesh arrangement:

- Three elements over the web height of the girders, floors in double bottom and over stringer webs in side wing structures.
- One element between each longitudinal.
- Four elements between each floor.
- Access holes and larger openings in webs, girders and stringers can be considered in the analysis model in several alternatives, i.e. by including holes as-is in the model, by reduced web thickness or by due consideration in the stress evaluation stage.

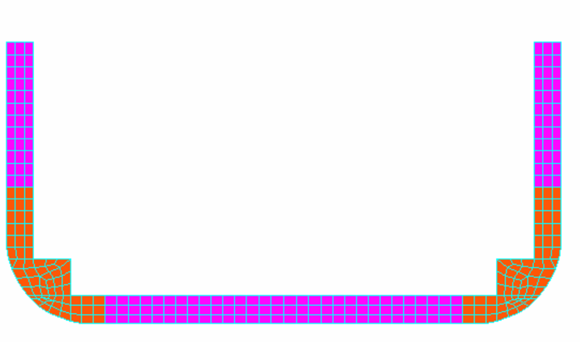

Figure 5-3
Typical mesh arrangement of transverse web

5.4 Boundary conditions

Symmetric boundary conditions are in general to be applied at the ends of the model. If half breadth model is used, symmetry shall be applied along the centreline of the model.

The model may be supported in the vertical direction by applying springs at the intersection lines between the side/inner side and the watertight transverse bulkheads.

The spring constant may be calculated as follows, ignoring the effect of bending deflection:

$$K = 8\, A_s \cdot E\, /\, (\, 7.8 \cdot 3 \cdot l_h\,)\quad [\mathrm{N/mm}]$$

where:

A_s = shear area for double side [mm^2]
E = $2.06 \cdot 10^5$ N/mm^2
l_h = length of one cargo hold [mm].

Alternatively, vertical forces may be applied in the same intersections and the total vertical forces shall balance the unbalanced force between downward and upward forces in the whole model. The model will then be restrained in vertical direction at the intersections in way of transverse bulkheads.

Table 1 Boundary conditions for containers LC1 to LC7 except LC3 and LC4

Location	Displacement			Rotation		
	δx	δy	δz	θx	θy	θz
Plane A	X	-	-	-	X	X
Plane B	X	-	-	-	X	X
Line A, B			S/F_v			
Point a, b	-	X	-	X	-	X

X	Restricted from displacement or rotation
-	Free
S	Springs (S/F_v means springs or forces)
F_v	Vertical forces. When vertical forces are applied the model must in addition be restricted from translation in the vertical direction by fixing it in one node, taken as the intersection between, outer side, deck and one transverse bulkhead.

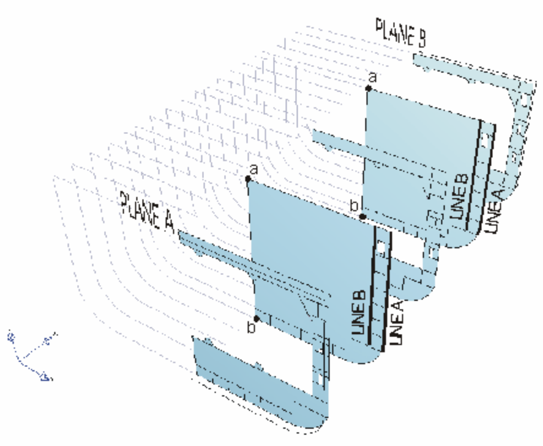

Table 2 Boundary conditions for containers LC3 and LC4

Location	Displacement			Rotation		
	δx	δy	δz	θx	θy	θz
Plane A	X	-	-	-	X	X
Plane B	X	-	-	-	X	X
Line A, B			S/F_v			
Line C	-	X	-	X	-	X

X	Restricted from displacement or rotation
-	Free
S	Springs (S/F_v means springs or forces)
F_V	Vertical forces. When vertical forces are applied the model must in addition be restricted from translation in the vertical direction by fixing it in one node, taken as the intersection between, outer side, deck and one transverse bulkhead.

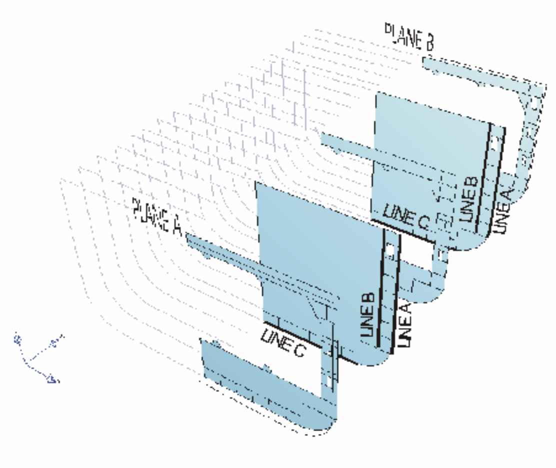

Figure 5-4
Boundary conditions for up-right and heeled load cases

5.5 Load cases

Load cases for the cargo hold analysis will generally correspond to those described in the Rules for Classification of Ships Pt.5 Ch.2 Sec.6 C400 for girder systems.

The hatch covers need not be included in the model, but the container loads on the hatch covers must be properly included in the analysis by consideration of frame and support arrangement of hatch covers.

In general the following load components shall be included in the cargo hold model:

— Sea pressure including dynamic loads (when relevant) by pressure loads.
— Container loads in terms of concentrated load at each contact point to the hull structure including dynamic loads (when relevant).
— On deck container load including the weight of hatch covers shall be considered. The load transfer from the hatch covers shall properly take into account the actual force transfer to the hull structure through the girder system of the hatch cover and the support arrangement on the hatch coaming.
— For on-deck containers, the longitudinal and transverse accelerations are calculated at the mid-height of the container stack.
— The number of tiers in each stack and the mass of the containers of each stack shall be based on the maximum given in the specification or the "Trim and Stability Booklet".
— In general, no wind force needs to be considered for the container stacks on deck.
— For containers in hold, the transverse and longitudinal forces (i.e. accelerations) are calculated at the centre of each container and applied to the transverse bulkhead members in way of the cell guide.
— For containers in hold, the longitudinal and transverse acceleration will vary for each container. A group consideration can then be applied, i.e. same longitudinal or transverse acceleration can be applied to several containers within the same group.
— Acceleration effects shall be included in cargo load description for LC1-LC6.

Note:

The self weight of the hull structure should be included in the cargo hold analysis.

---e-n-d---of---N-o-t-e---

The load cases as described in the text below are to be examined. The container load in fore and aft end bays may in general be for 40 ft container stacks.

For ships with a comprehensive class notation with respect to direct calculations (e.g. CSA-2 class notation), it is advised to carry out 3 additional purely dynamic load case. For further information, references is made to section 16.4.

5.5.1 Maximum cargo at reduced draught (LC1)

Maximum cargo mass (20 ft containers as relevant) in considered hold in seagoing upright condition at reduced draught.

The adjacent holds are to be assumed empty, and the reduced draught is generally not to be considered larger than 0.8T.

This load case is for dimensioning of bottom transverse members of support bulkheads.

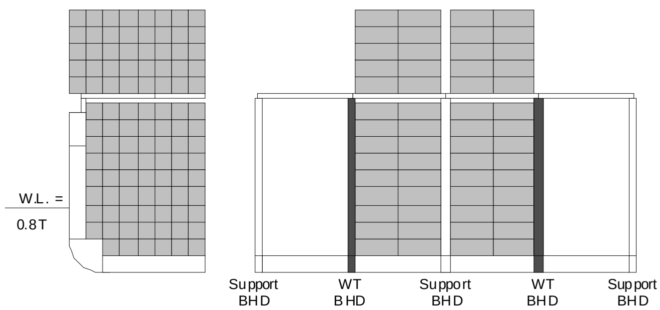

Figure 5-5
Load Case 1

5.5.2 Minimum cargo at scantling draught (LC2)

In general, any one 40 ft bay of the cargo hold and the deck space above are to be assumed empty. For empty hold conditions, it is generally accepted to apply static external sea pressure only.

In the remaining cargo space (in holds and on deck above) the cargo mass may not be greater than the maximum cargo mass based on 40 ft container stowage, if applicable, given according to Pt.5 Ch.2 Sec.6 C202.

As an alternative to the empty hold condition, a specified minimum cargo limit in the hold may be considered if this can represent realistic operating conditions better than the Rule defined loading condition. If a minimum cargo condition is applied, the external sea pressure is normally to be taken as the sum of the static and dynamic pressure as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.4 C200.

Ballast in double bottom can be taken into account if ballast is used throughout the operation of the ship.

If a minimum cargo limit is applied instead of empty hold or if ballast is assumed in double bottom, this should be clearly defined in the appendix to Classification certificate.

This load case will be dimensioning bottom plating, double bottom girder and floors and support bulkhead.

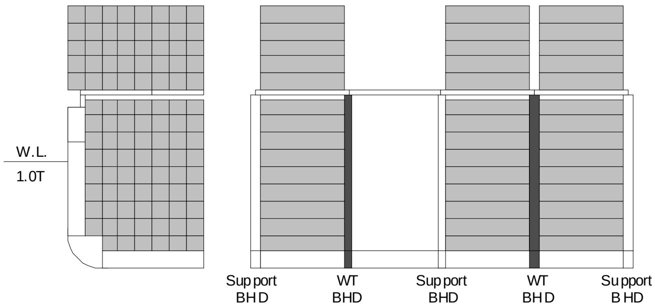

Figure 5-6
Load Case 2

5.5.3 Heeled condition, maximum cargo (LC3)

Container cargo arrangement in hold and on deck is identical to LC1 in heeled condition.

This load case is for dimensioning of the upper part of side structure and support bulkhead.

The transverse acceleration is to be taken as given in section 3.3.2 and is to be combined with the vertical acceleration of gravity.

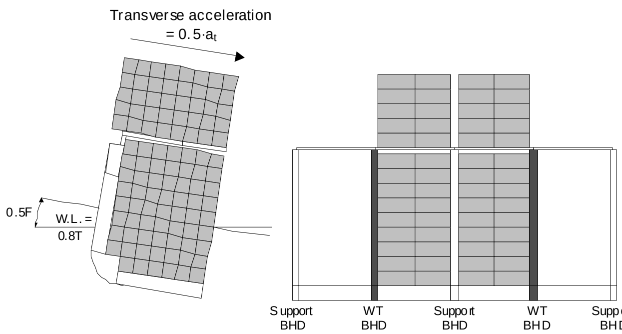

Figure 5-7
Load Case 3

5.5.4 Heeled condition, minimum cargo (LC4)

Container cargo arrangements in hold and on deck are identical to LC2 in the heeled condition.

This load case is dimensioning of the lower part of side structure and support bulkhead.

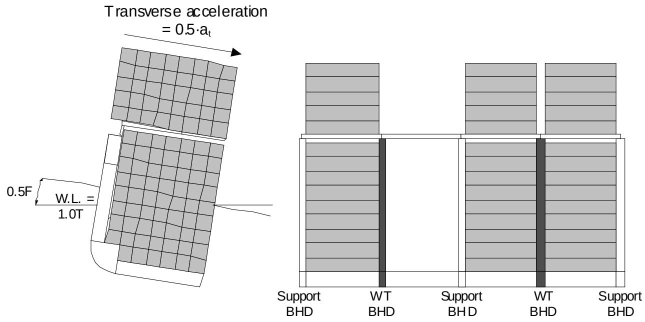

Figure 5-8
Load Case 4

5.5.5 Maximum cargo in hold and on deck, longitudinal acceleration (LC5)

Maximum mass of cargo in hold and on deck with dynamic longitudinal acceleration, for dimensioning of support- and watertight bulkheads.

The longitudinal acceleration is to be taken as given in section 3.3.2. and is combined with the vertical acceleration of gravity.

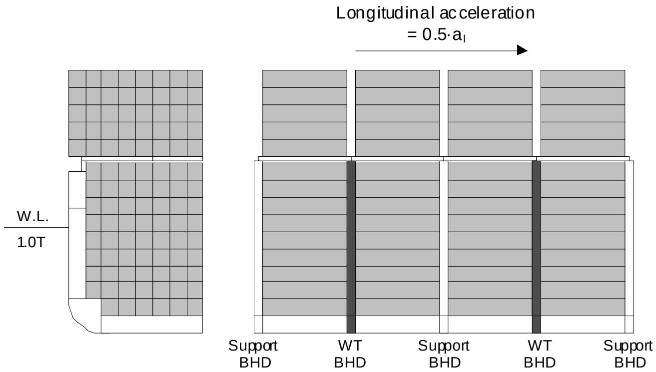

Figure 5-9
Load Case 5

5.5.6 Maximum cargo on deck and minimum cargo in hold below (LC6)

Maximum specified mass of cargo on deck with minimum cargo in hold below in upright seagoing condition at full draught.

This load case is dimensioning the vertical girders of the support bulkhead.

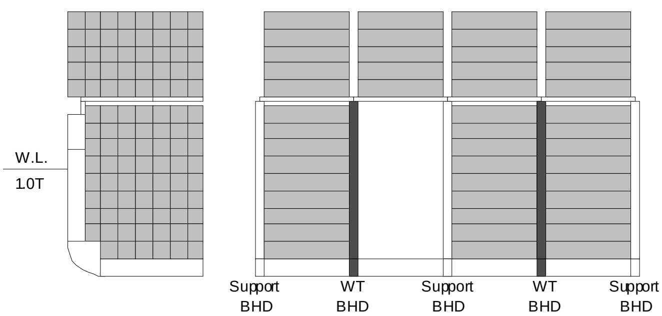

Figure 5-10
Load Case 6

5.5.7 Flooded damage condition (LC7)

Maximum of the calculated damaged draught will be utilized for the calculation. If not available in early design, a floodikng height up to the freeboard deck level (normally 2nd deck) may be assumed.

This load case is primarily intended used for the dimensioning of transverse watertight bulkhead girder structure.

5.5.8 Additional load cases

For design with deck hatch girder arrangement, additional load case may be considered according to special loading patterns.

5.6 Allowable stresses

Allowable stresses in typical primary members are shown in Table 5-1.

The following should be noted:

— f_1 is material factor (see Table 12-1).
— Longitudinal hull girder stress due to semi-global bending of the cargo hold model may be deducted. By semi- global bending is meant the vertical bending effect of the cargo hold model when exposed to the loads described in section 5.5.
— The allowable shear stress is a mean value of all elements over the web height. In case openings are not modelled, the resultant shear stress should be adjusted according to the actual opening ratio.

Table 5-1 Allowable stresses of primary members

Structures/ Load cases	*Nominal stress, σ [N/mm^2]*	*Shear stress, τ [N/mm^2]*		*Equiv. stress, σ_e [N/mm^2]*
		One plate flange	*Two plate flange*	
Longitudinal girders	190 f_1 1)	90 f_1 100 f_1 2)	100 f_1 110 f_1 2)	
Transverse and vertical girders	160 f_1 180 f_1 2)	90 f_1 100 f_1 2)	100 f_1 110 f_1 2)	180 f_1 200 f_1 2)
Face plate of primary members Web stiffeners parallel to the face plate	160 f_1 180 f_1 2)			
Flooding condition	220 f_1	120 f_1	120 f_1	

1) Includes hull girder stress at a probability level of 10^{-4}
2) For tank test condition as described in Appendix E

5.7 Buckling control

Buckling control to be carried out.

Table 5-2 gives examples of areas to be checked for buckling, and the applicable method and acceptance criteria based on formulae as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.13.

For flooding conditions, elastic buckling ($\sigma_{el} < \sigma_a/\eta$) in plate panels may be accepted. An acceptable method for evaluating ultimate compressive stresses above the critical buckling stress in the elastic range ($\sigma_{el} < 0.5\ \sigma_f$) is given in the Rules for Classification of Ships Pt.3 Appendix A.

Table 5-2 Acceptance criteria and method

Structural Item	*Acceptance Criteria*
Longitudinal structures: — bottom shell, inner bottom, side shell, deck and longitudinal bulkhead — longitudinal girders in double bottom and double side	1) Bi-axial buckling to be analysed based on longitudinal stress and mean transverse stress and allowable usage factors below: — η_X, η_Y = 1.0 included hull girder stress at a probability level of 10^{-8} — η_X, η_Y = 0.85 included hull girder stress at a probability level of 10^{-4} 2) Uni-axial in transverse direction to be analysed based on mean transverse compressive stress with ψ = 1 and allowable usage factor, η = 0.8
Plate of Watertight Transverse Bulkhead	1) Uni-axial in transverse direction to be analysed based on mean transverse compressive stress with ψ = 1 and allowable usage factor, η = 0.8 2) Bi-axial buckling to be checked where relevant
Transverse and vertical structures: — D/B floors, side transverses — cross-deck structures — vertical/horizontal girders on Transverse Bulkhead.	1) Buckling to be analysed based on mean shear stress with allowable usage factors, η = 0.85 2) Uni-axial in transverse direction to be analysed based on mean transverse compressive stress with ψ = 1 and allowable usage factor, η = 0.8 3) Bi-axial buckling to be checked where relevant

6. Rule torsion calculation

6.1 General

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 (still water torsion induced by cargo and unsymmetrical tank arrangement, etc. and wave torsion induced by oblique wave encounter) and the horizontal bending moments shall also be included in the hull girder strength calculation.

The Rule torsion calculation procedure is generally sufficient for container ships of standard size and structural arrangement.

For ships of extraordinary size and structural arrangement, a more detailed global torsion analysis, e.g. the Level 3 or Level 4 analysis, is recommended.

6.2 Calculation procedure

Torsion response of main hull structures is to be calculated according to the following calculation procedure:

a) "Section Scantling" calculations for the midship section where the torsion response of the hull is calculated as longitudinal warping stresses and deformations along the cargo hold area.

b) 3-D Beam (beam analysis) calculation of upper hull structures is to be carried out for the warping deformations obtained by task a). The stress at the transverse box beam due to these deformations is to be included in the peak stress at the hatch corners only.

c) Other stress components such as vertical and horizontal bending moments is to be calculated using the section scantling output.

d) Total stress combination is to be carried out for transverse bulkhead locations according to the sign conventions.

e) Peak stress calculation by stress concentration along hatch corners shall be carried out using the stress concentration data found in the tables of section 14.

f) The flow chart in Figure 6-1 describes the procedure and tools that may be used for the torsion calculation.

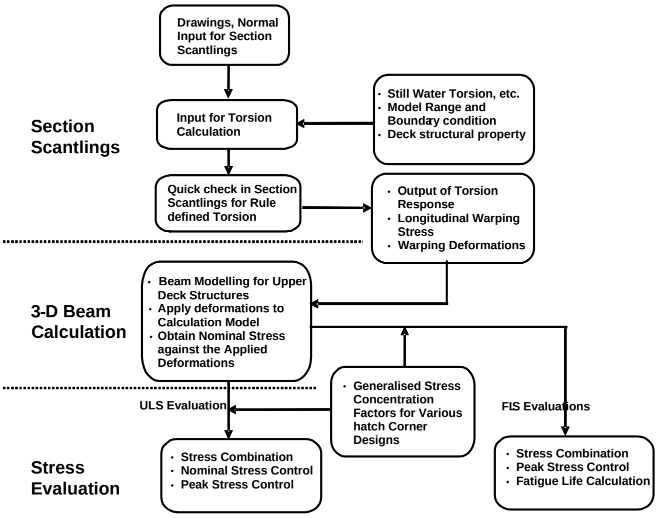

Figure 6-1
Flow chart for Rule torsion calculation

6.3 Stresses from Rule torsion analysis

For reference to the stresses in this section, see the Rules for Classification of Ships Pt.5 Ch.2 Sec.6.

The combined normal stress due to vertical and horizontal hull girder bending and due to torsion moment is not to exceed $195 f_1$ N/mm^2. In the deck and hatch coaming, the combined stress including stress due to warping deformations is not to exceed $225 f_1$ N/mm^2.

The combined stress may be taken as:

$\sigma = |\sigma_{STAT} + \sigma_{DYN}|$ [N/mm^2]

σ_{STAT} = $\sigma_S + \sigma_{ST}$
σ_{DYN} = $\sigma_W + \sigma_{WH} + \sigma_{WT}$
σ_S = hull girder stress due to still water bending moment (= $M_S (z_n - z_a) \cdot 10^5 / I$)
M_S = design still water bending moment [kNm]
z_n = vertical distance in meters form base line to neutral axis of the hull girder
z_a = vertical distance in meter form base line to the point in question
I = moment of inertia in cm^4 of hull girder about the horizontal axis at the section considered
σ_{ST} = warping stress and stress due to warping deformations in N/mm^2 at position considered for the given still water torsional moment distribution, M_{ST}.
σ_W = hull girder stress due to vertical wave bending moment (= $M_W (z_n - z_a) \cdot 10^5 / I_H$)
M_{WR} = reduced vertical wave bending moment to be considered for the combined response
= 0.45 M_W in general
M_W = vertical wave bending moment as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.5 B201
σ_{WH} = hull girder stress due to horizontal bending moment (=$M_{WH} \cdot y_a \cdot 10^5/I_H$)
M_{WH} = horizontal wave bending moment as given in the Rule for Classification of Ships Pt.3 Ch.1 Sec.5 B205
I_H = moment of inertia (cm^4) of hull girder about the vertical axis at section considered
y_a = distance in m from centre line to position considered
σ_{WT} = warping stress and stress due to warping deformations in N/mm^2 at position considered due to the wave torque, M_{WT}.
M_{ST} = design still water torsional moment in kNm over ship length
= 0.3 LB^2 [kNm] minimum
M_{WT} = wave torsion [kNm] as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.5 B206

There are two different expressions for the torsion moment M_{WT}, one giving highest torsion in the aft body (M_{WT1}) and one giving highest torsion in the fore body (M_{WT2}).

$M_{WT1} = K_{T1} L^{5/4} (T + 0{,}3 B) C_B z_e + K_{T2} L^{4/3} B^2 C_{SWP}$

$M_{WT2} = K_{T1} L^{5/4} (T + 0{,}3 B) C_B z_e - K_{T2} L^{4/3} B^2 C_{SWP}$

where

K_{T1} = 1.40 sin(360 x/L)
K_{T2} = 0.13 (1- cos (360 x/L)
C_{SWP} = AWP/(LB) (= 0.85 in general for container ships)
A_{WP} = water plane area of vessel in m^2 at draught T
z_e = distance in m from the shear centre of the midship section to a level 0.7T above the base line
x = distance in m from A.P. to section considered

For further explanation of the torsion moment, see also section 6.5.

6.3.1 Vertical bending stress calculation (σ_{Sv}, σ_{Wv})

Vertical bending stress shall be calculated based on the vertical hull girder bending moment (still water plus wave bending moment) divided by the hull girder vertical section modulus at the upper deck or hatch coaming top as found relevant.

6.3.2 Horizontal bending stress calculation (σ_{WH})

Horizontal bending stress shall be calculated based on the hull girder horizontal bending moment divided by the hull girder horizontal section modulus at the location of interest.

6.3.3 Warping stress calculation (σ_{ST}, σ_{WT})

Warping stress can be calculated by Section Scantlings using torsion calculation part for the midship section.

6.3.4 Bending stress due to warping deformation

The bending stress due to forced warping deformations are denoted σ_{bsw} (static) and σ_{bww} (dynamic). A simple 3-D beam calculation can be carried out to obtain these additional stresses induced by warping deformations in way of cross deck structures.

The warping deformations may be obtained from Section Scantlings output and applied to a simple beam model as forced displacements.

For further details on how to calculated σ_{bsw} and σ_{bww}, references are made to section 6.6.

6.4 Stress combination and sign convention

6.4.1 Stress combination

In a sea condition with maximum torsion moment, the ship encounters oblique waves with wave length normally between 0.6 to 0.8 of ship length. In this circumstance, the maximum vertical wave bending moment is unlikely to appear simultaneously with the maximum of horizontal bending moment and torsion moment.

To compensate for the fact that the maximum values of the stress components do not appear simultaneously, only 45% of maximum vertical wave bending moment is to be used for torsion cases as shown in Table 6-1. σ_{MWT1} and σ_{MWT2} denote the stresses due to the torsion moment M_{WT1} and M_{WT2}; respectively.

Table 6-1 Weight factors for stress combination

Case	Stress Components						
	Vertical still water Bending	*Vertical wave Bending*	*Horizontal Bending*	*Still water torsion (Warp.)*	*Wave torsion (Warp.)*	*Still water Torsion (Defl.)*	*Wave Torsion (Defl.)*
	σ_S	σ_W	σ_{WH}	σ_{ST}	σ_{WT}	σ_{bsw}	σ_{bww}
Case 1	100%	45%	100%	100%	σ_{MWT1}	100%	100%
Case 2	100%	45%	100%	100%	σ_{MWT2}	100%	100%

6.4.2 Sign convention

In general, horizontal wave bending and longitudinal warping stress in deck have opposite signs in the cargo hold area.

This will normally change near the engine room bulkhead for Case 1, where the longitudinal warping and horizontal bending stress may have the same signs.

The calculation shall be carried out for port and starboard side to cover all relevant stress combinations.

The vertical bending stress is always to be taken as positive in the deck structures due to the hogging condition.

6.5 Calculation details - ULS cases

The torsion response analysis will be based on results from Nauticus Section Scantlings. The calculation gives the results for two different Rule defined torsion cases, i.e. Case 1 (M1+M2=M_{WT1}) and Case 2 (M1–M2=M_{WT2}).

M1 and M2 in Section Scantlings refer to the following two parts in the Rule formula:

$$M1 = K_{T1} L^{\frac{5}{4}} (T + 0.3B) C_B z_e$$

$$M2 = K_{T2} L^{\frac{4}{3}} B^2 C_{SWP}$$

K_{T1} and K_{T2} are found in section 6.3.

The torsion moment along the ship length is shown in Figure 6-2.

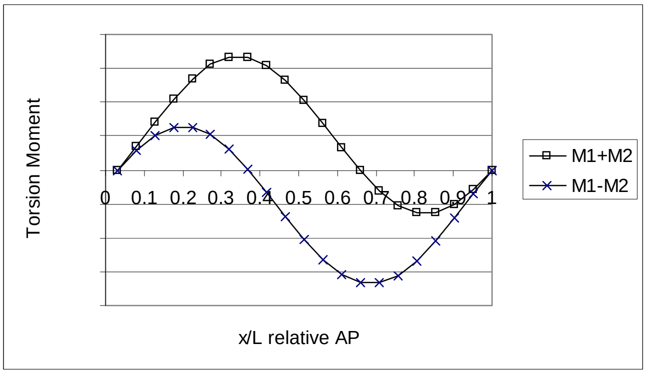

Figure 6-2
Rule torsion distribution

The warping stress is given directly by Section Scantlings, but the bending stress induced by warping deformation is to be added for the upper deck structure. For the bilge area, the additional warping deformation stress calculation is not necessary.

6.6 Calculation of bending stress due to warping deformation

In order to find the stress component due to relative warping deformations, a beam model of the upper deck structure is to be established as shown in Figure 6-3.

The longitudinal and transverse warping displacements obtained from Nauticus Section Scantlings calculation shall be applied as forced displacement to each transverse bulkhead location at the sides.

The beam model for the upper part of the hull shall include the longitudinal and transverse deck strips with relevant width of the side shell (sheer strake), longitudinal bulkhead, hatch coaming and transverse bulkhead as flange.

The flange breadth of the beam element shall be equivalent to the breadth used in Nauticus Section Scantlings for the torsion response calculation.

6.6.1 Length of warping deformation model

The calculation model extends from B/5 aft of the engine room bulkhead to the bulkhead section in the forward of cargo hold area where the hatch opening size remains unchanged.

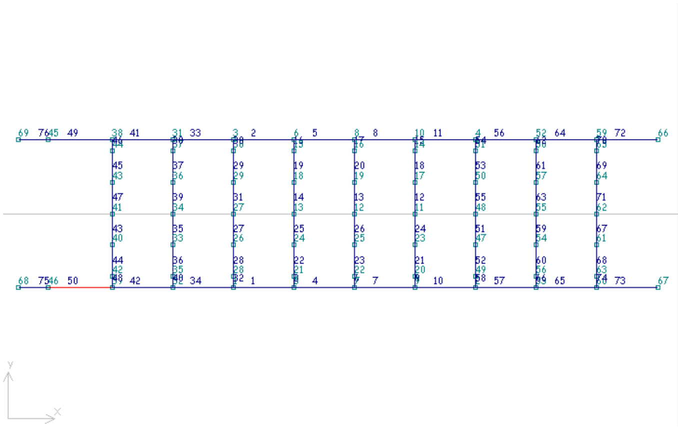

Figure 6-3
Example of beam model for stress calculation due to warping deformation.

The transverse beam in the beam model shall be positioned in the centre line of the transverse box beam.

The longitudinal beam in the beam model shall be positioned along the inner side.

6.6.2 Beam section

The same cross sectional properties as used in the Nauticus Hull Section Scantlings should in general be used in the Beam model.

For the longitudinal deck strip, the flange of the beam may be assumed from 2nd deck to hatch coaming top level at the longitudinal bulkhead side and to upper deck for the side shell.

If the plate thickness varies in the area, then an equivalent thickness is to be applied.

Longitudinal deck strips may be modelled as an I-section, where the deck structures are idealised as in Figure 6-4.

Figure 6-4
Idealisation of beam cross section (example)

The transverse deck beam may also be modelled as an I-section, but both flanges are to be of the same breadth. The flange breadth should be taken from 2nd deck level to the hatch coaming top.

The end parts of the transverse box beam shall be modelled with increased dimensions to reflect the local strengthening in the hatch corner area, i.e. increased thickness in deck plate and both flange (bulkhead) plates as per actual design.

6.6.3 Loads and boundary conditions

The forced displacements shall be applied at all nodes at sides as per the results of the torsion calculation.

The displacements at upper deck in Section Scantlings results shall be applied as forced displacements.

Transverse displacements are to be applied with the same signs on both sides of the ship, while longitudinal displacements are to be applied with opposite signs at each sides.

The longitudinal displacements from Nauticus Section Scantlings are relative displacement between port and starboard side, hence half the displacement will be applied to each node at port and starboard side.

6.7 Stress evaluation

Nominal stress in torsion shall be the sum of all coincident stress components including the bending stress σ_{bsw} and σ_{bww} in the longitudinal deck and hatch coaming structure due to warping deformation taking the sign conventions into consideration.

The bending stress σ_{bsw} and σ_{bww} may be taken from the beam model as half of the difference in stress level in the longitudinal beams forward and aft of the cross deck beam positions.

The bending stress in the cross deck due to forced warping deformations is to be included for evaluation of peak stresses in the hatch corners only.

7. Global Structural Model

7.1 General

The global analysis model is a relatively coarse FE model.

The purpose of the global hull model is to obtain a reliable description of the overall hull girder stiffness to determine the global stress distribution in primary hull members.

The local stress distributions is assumed to be of less importance.

Stresses in girders, frames, transverse webs, etc. will be utilised for yield assessments as well as for buckling assessment for major parts of the ship.

7.2 Model extent

All structural parts of the ship shall be included in the model.

The model is also to include the deckhouse, to extend over the full breadth and depth of the vessel and to represent the actual geometry of the vessel with reasonable accuracy.

All primary longitudinal members shall be included and all primary transverse members, i.e. watertight bulkhead, non-watertight bulkhead, cross deck structures and transverse webs shall be represented in the model.

Structures not contributing to the global strength may be disregarded.

The omission of minor structures may be accepted on the condition that the omission does not significantly change the deflection of structure.

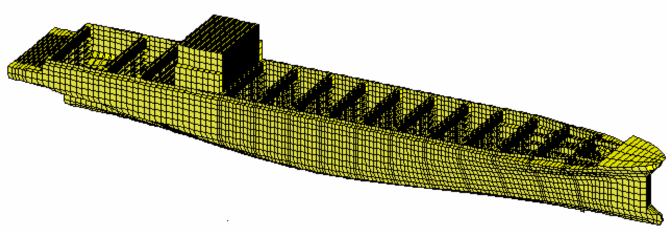

Figure 7-1
Global structural analysis model

7.3 Model idealization

All primary longitudinal and transverse structural members, i.e. shell plates, deck plates, bulkhead plates, stringers and girders and transverse webs shall in general be modelled by shell or membrane elements.

The scantlings for longitudinal members may be modelled with gross scantlings. For the transverse members, they shall be modelled with reduced scantlings, i.e. corrosion addition according to the Rules for Classification of Ships shall be deducted from the actual scantlings. Otherwise, these shall be taken into account during the stress evaluation.

Beams, longitudinals and stiffeners shall be described by beam or truss elements.

Buckling stiffeners of less importance for the stress distribution may normally be disregarded.

7.4 Mesh arrangement

In general 4-node shell or membrane elements in combination with 2-node beam or truss elements shall be used. The elements shall be rectangular as far as possible.

The use of 3-node shell or membrane elements shall be limited as far as practicable.

The mesh size shall be decided considering proper stiffness representation and load distribution.

The standard mesh arrangement is normally to be such that the grid points are located at the intersection of primary members, but may be adjusted to achieve the proper stress investigation for fore and aft part of the cargo hold areas.

In general the element size may be taken as one element between longitudinal girders, one element between transverse webs and one element between stringers and decks. If the spacing of primary members deviates much from the standard configuration, the mesh arrangement described above shall be reconsidered to provide a proper aspect ratio of the elements and proper mesh arrangement of the model.

The deckhouse shall be modelled using a similar mesh idealisation including primary structures.

Local stiffeners which are considered not important for the overall design check, may be lumped to neighbouring nodes.

7.5 Non structural elements

In case a mass model is not required (see section 9), the mass elements which do not contribute to the structural strength may be excluded in the model. This includes for instance hatch covers, main engine, auxiliary engine, propeller and rudder.

In case a mass model is to be included in the FE model (see section 9), then all masses need to be modelled.

Containers on deck will then be modelled by shell elements or equivalent to represent their mass effect properly. Containers in hold will also be included in the model as shell elements or equivalent to represent their mass effect properly.

Rudder and associated components will be modelled by shell elements to represent their mass effect properly.

Hatch covers will be included as concentrated mass in the relevant locations at the hatch coaming top level.

Other mass elements such as main engine, auxiliary engines will also be included as mass elements in the relevant locations.

It is important to make sure none of these idealised mass elements contributes to structural stiffness in the model.

7.6 Boundary conditions

To eliminate the rigid body motions of the analysis model, total six (6) boundary constraints will be introduced. Other boundary conditions may be used if desirable.

The fixation points shall be located away from the areas where the stress is of interest, as the loads transferred from the wave load analysis may lead to unbalance, although small, in the model.

However, special care shall be taken to ensure that there is, within practical limits, little or no unbalanced forces and moments of the six boundary constraints.

Figure 7-2 shows an example of applicable boundary conditions. The global model is supported in three positions, one at the bow bottom (fixed in vertical and transverse direction), one at the aft bottom (fixed for translation along all three axes) and one position at upper deck level aft (fixed in transverse direction).

The out of balance forces at constraints may be avoided using an inertia relief function or an equivalent means provided by the analysis software. The applied forces shall be well balanced by inertia loads distributed throughout the analysis model induced by an acceleration field.

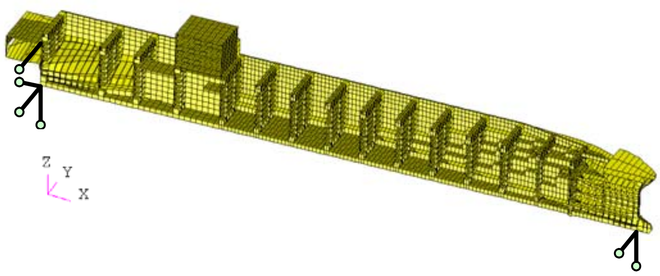

Figure 7-2
Boundary condition (example)

8. Simplified Wave Load Application

8.1 General

The following chapter describes a simplified way of applying loads on a global FE model. The loads may be those according to the Rules for Classification of Ships or loads based on a direct wave load analysis.

8.2 Vertical still water bending moment

— Design still water bending moment distribution over the entire ship length shall be examined.
— The design still water bending moment envelop can be applied in the FE model using concentrated loads to the side shell along the ship length. The concentrated forces (shear forces) are to be appliedin way of the 2nd deck (see Figure 8-1). It is important to make sure the forces represent actual hull girder force and bending moment envelopes within a reasonable accuracy.
— Local load such as containers in hold and on deck, tank pressure, etc. may not be included in the model.
— The analysis shall be run statically, i.e. no acceleration and mass effect will be included.

8.3 Wave bending moment

— Vertical wave bending moments will be applied using concentrated vertical forces (shear force) to the side shell along the ship length, as for still water bending moment (see Figure 8-1).
— For easy stress combination, it is recommended to split the still water bending moment and the wave bending moment into separate load cases.

8.4 Horizontal bending and wave torsion

— Horizontal bending and wave torsion will be applied using horizontal forces and coupled vertical forces.
— The forces should be applied in way of the 2nd deck.
— Horizontal bending moment will be represented in the model using horizontal forces (see Figure 8 1). The horizontal force F_H may be calculated based on the Rule formula for the horisontal wave bending moment,

$$F_H = d^2M_{WH}/dx^2$$

(the second derivative of the horizontal wave bending moment).

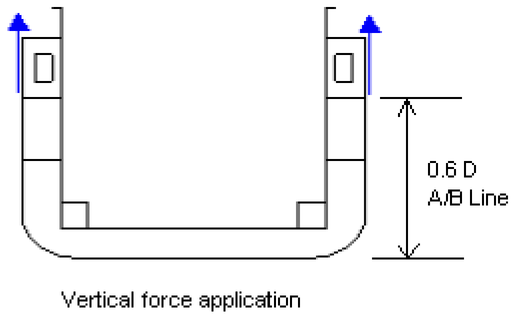

Figure 8-1
Application of vertical force

— The DNV's Rules for Classification of Ships require that two different combinations for the horizontal and vertical components of wave torsion are evaluated, where the torsion induced by the horizontal component is termed M1 and the torsion induced by the vertical component is termed M2 A coupled and a counter acting load combination (M1+M2 and M1-M2) is to be evaluated. These two different rule defined wave torsion cases are denoted M_{WT1} and M_{WT2}
— The application of the horizontal force F_H to induce horizontal bending results in a torsion moment M_{FH}. This causes the majority of the wave torsion component caused by horizontal wave pressure load (the term M1 in section 6.5) to be imposed on the model by the horizontal forces. The torsion moment, M_{FH},over the length of the ship caused by the horizontal forces F_H may be taken as the horizontal force multiplied by its distance to the shear centre of the midship section. The torsion, M_{FH}, induced by the horizontal load F_H must therefore be subtracted from the term M1. Hence the total torsion to be applied as coupled vertical forces may be expressed as:

$M_{WT1}' = (M1 - M_{FH}) + M2$

$M_{WT2}' = (M1 - M_{FH}) - M2$

where

M_{WT1}' and M_{WT2}' = Torsion moments to be applied as coupled vertical forces.

The vertical forces to be applied is calculated as

$$(d(M_{WT1}')/dx)/B \text{ and } (d(M_{WT2}')/dx)/B$$

(B is the vessel breadth where the vertical forces are applied)

M2 = The torsion component caused by the vertical wave pressure distribution as given in section 6.5
M1 = The torsion component caused by the horizontal wave pressure as given in section 6.5
M_{FH} = The torsion induced by the applied horizontal force for inducing horizontal bending.

— The above force application for inducing torsion can be substituted by moment application at the shear centre of the sections with a rigid plane arrangement.

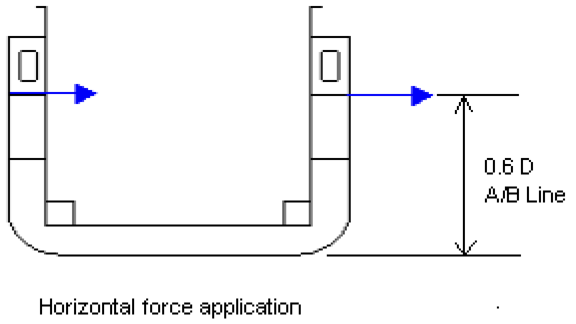

Figure 8-2
Application of horizontal force

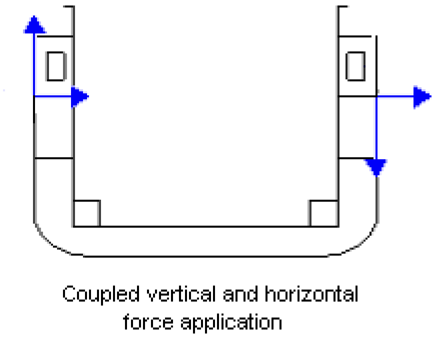

Figure 8-3
Application of combined vertical and horizontal force

8.5 Still water torsion

a) Still water torsion may be assumed constant over the length of the hull.

b) Still water torsion moment may be applied by using coupled vertical forces at both sides as for wave torsion.

9. Mass Model

A detailed mass model needs to be derived for cases when a direct wave load and load application procedure (see section 10) are to be carried out. If only the wave loads are to be calculated without load application (i.e. Level 3 analysis), then only a mass model is required during the wave load analysis. If also the wave loads should be applied consistently to the FE model (i.e. balance between inertia forces and sea pressure), then also a mass model needs to be made as part of the FE model (i.e. Level 4 analysis).

The global analysis model has to represent the actual mass distribution of the hull structure as well as other weight components with a reasonably good accuracy.

In order to avoid the unacceptable unbalanced forces (normally more than about 3% of total load), the mass distributions of the global analysis model shall be as accurate as possible.

The mass model applied in the global FE analysis and the wave load analysis has to be identical in order to ensure a well balanced FE model.

The hydrodynamic analysis needs a correct mass description to produce correct motions and forces, while global/local stress patterns of the structural analysis are affected by the mass description.

The light ship weight components such as hull structure, machinery and equipment, out fittings, consumables, and etc. will commonly be used for the different loading conditions.

Other weight components shall be defined separately for each loading condition.

All force components obtained from the direct wave load analysis are to be in a state of equilibrium, and it is of importance that they, within a reasonable limits, are to be kept unchanged in the global structural analysis (see also section 10.8.5).

9.1 Light ship weight

The weight of the structure is obtained by applying density to the applied steel material.

In order to be able to tune the position of the centre of gravity and verify the weight distribution in an easy way, different material densities can be used along the hull length. Typically, one material density is applied over one bay or hold.

The remaining part of the light ship weight such as machinery, outfitting and consumables will be represented by concentrated mass component at the centre of gravity of each component. The weight of a component may be divided into several mass points if the component are too heavy (e.g. main machinery).

All masses must be attached to the surrounding structure.

The density of each weight group will be adjusted in order to achieve the correct mass distribution and the position of the centre of gravity. The whole analysis model shall be in compliance with the actual light ship weight distribution. This often requires an iteration process for tuning the mass distribution.

9.2 Ballast water and tank content

The liquid mass in tanks will be represented by point mass components which are distributed to the node points surrounding the tank. It is not necessary to include the local pressure distribution of the tanks in the global FE analysis.

9.3 Heavy weights

Heavy weights (deck equipment and machinery etc.) can be modelled as point masses attached to the surrounding structure.

9.4 Container loads

On-deck containers can be modelled by using shell elements or solid elements, which may be connected to the main hull by either springs or truss (bar) elements.

The spring or truss (bar) elements will be idealised with a small stiffness not to an influence to the stiffness of the hull girder.

Containers may also be connected to the hull structure directly without any spring or truss elements. The container stacks then need to be modelled with very low Young's modulus in order not contributing to the hull girder stiffness.

The centre of gravity for on-deck containers shall be correctly represented to get a realistic heeling moment when they are exposed to transverse acceleration.

In-hold containers can be represented by shell elements with low Young's modulus. The shell elements may be included in the global model at the transverse and longitudinal bulkhead locations.

For in-hold containers modelled by shell element, special attention will be paid to the vertical and horizontal force transfer to surrounding structure in order not to influence the overall strength. The connection between the shell elements and the transverse bulkhead should only transfer longitudinal forces (i.e. no vertical nor transverse forces). The connection of the shell elements to the longitudinal bulkhead should only transfer the transverse forces (i.e. not vertical nor longitudinal forces). The connection of shell elements to the bottom should transfer vertical forces only (i.e. not longitudinal nor transverse forces).

9.5 Generation of other load components

Hydrodynamic pressure loads combined with static pressure are to be applied to the analysis model with coincident accelerations. The pressures will be applied to the wet part of the hull.

10. Wave Load Analysis

10.1 General

Level 3 and Level 4 analysis require a direct wave load analysis to be carried out. The outcome of such analyses are motion calculation, accelerations, hull girder loads and local pressures.

10.2 Objectives

The objectives of the wave load analysis are:

— To calculate the sea-keeping characteristics of the vessel including accelerations.
— To calculate the global hull girder loads distributed over the vessel length.
— To establish design waves for ULS conditions for further non-linear wave load calculations.
— To calculate ULS load cases for global strength, buckling and yield checks.
— To calculate FLS load cases for the selected hatch corners and typical longitudinal connections in side shell and bilge area.

10.3 Numerical tools

The applied tools for calculations of wave loads should be based on recognised software. As recognised software is considered all wave load programs that can show results to the satisfaction of the Society. Forward speed effects have to be properly taken care of. Additionally, non-linear effects have to be included in extreme sea conditions.

10.4 Type of analysis

Typically, two different types of wave load analyses can be carried out. These are:

— ULS (Ultimate Limit State) analysis intended to calculate hull girder loads, local sea pressure and motions in extreme environmental conditions.
— FLS (Fatigue Limit State) analysis intended for calculation of dynamic loads used for fatigue assessment of critical details of the structure.

The scope of work and the calculation procedures will differ depending on what type of analysis that is carried out.

10.5 Linear versus non-linear analysis

Linear wave load analysis is in general sufficient for the fatigue assessment (FLS).

The ULS analysis are carried out using a combination of linear and non-linear analysis. The long term response is first calculated using a linear assumption. The linear long term response is basis for the establishment of design sea states. Non-linear analysis are carried out for the design sea states

10.6 Loading conditions

The following loading conditions (mass distribution) should be analysed:

Stress and buckling check (ULS):

— Maximum still water hogging moment amidships (scantling draught)
— Maximum still water sagging moment (or minimum still water hogging moment if applicable) amidships (scantling draught)

Fatigue analysis (FLS):

— Homogenous loading condition with high GM (design draught)
— Ballast condition

The loading conditions for the ULS analysis should represent the design still water moment for the vessel. These loading conditions are usually not included in the trim and stability booklet.

For the loading condition used for fatigue analysis (FLS), due attention should be paid to the GM value. Amongst several homogenous loading conditions with similar still water hogging moment amidships, the condition with the higher GM value should be selected. The reason for this is to have larger roll motions and therefore higher torsion moment on the hull girder.

10.7 Wave load analysis parameter

Wave period:
The wave load analysis should be carried out for relevant wave periods. Due attention should be paid so that the natural period in roll is included as part of the range of period. Wave periods (s) ranging between $0.25 \cdot L^{1/2}$ and $2.6 \cdot L^{1/2}$ are usually sufficient.

Wave direction:
The analysis should cover all wave headings with step of no more than 30 degrees (i.e. 0, 30, 60, etc).

Ship speed:
The wave load analysis should be carried out for speeds corresponding to 2/3 of the service speed. Additionally, for the ULS analysis, 5 knots should be used for calculation of the wave vertical bending moments.

Short term analysis:
The short term analysis should be carried out assuming a Pierson Moschowitz wave spectrum or equivalent. The wave spreading $\cos^2$ should be used and the probability should be the same for all wave headings.

Long term analysis:
The long term response analysis should be based on the short term analysis and a long term distribution of the waves (i.e. scatter diagram). The North-Atlantic wave scatter diagram is used for ULS analysis and World Wide trading scatter diagram should be used for the FLS analysis. However, the other wave scatter diagram can be used as per the owner’s requirement.

The details of the scatter diagrams can be found in Classification Note 30.7 “Fatigue assessment of ship structures”.

The long term analysis are based on standard linear wave load procedure utilising the principle of linear superposition.

Probability levels:
The long term response for ULS analysis should be based on a 20 year return period.

The loads used as basis for the fatigue analysis (FLS) should be at 10^{-4} probability level.

10.8 Stress and buckling check (ULS analysis)

10.8.1 General

The stress and buckling checks are carried out by defining load cases. The load cases are established based on the global hull girder loads in selected reference positions along the hull girder.

The long term hull girder loads are calculated at those reference positions. A design sea state is then defined to reproduce the (linear) long term response in the reference positions. Subsequently, a non-linear wave load analysis is carried out for the design sea states

10.8.2 Reference positions for hull girder loads

The long term hull girder loads are calculated for 3 position along the hull girder. These correspond to 0.25L, 0.5L and 0.75L from aft perpendicular. The positions in the fore ship (0.75L) and aft ship (0.25L) can be adjusted to the position were the bay width start reducing and a position immediate forward of the engine room bulkhead; respectively.

10.8.3 Selection of design sea state

By design sea state in this context is meant a regular design wave with given wave direction, wave period and wave height.

A design sea state is established to represent the long term response for the vertical bending moment and the torsion moment for each of the above reference positions. It is then assumed that the large hatch deflections will be covered by the condition for maximum torsion moment.

In some cases several design sea states are established for the torsion moment at the different reference positions. Example of such cases is when there is no clear dominating wave direction for the torsion moment. It is then recommended to establish design sea states based on several wave directions.

The design sea state (in this context a regular design wave) is determined as follows:

— *Wave heading* is selected as the wave heading where the long term value for the given response is maximum.
— *Wave period* is selected as the wave period where the transfer function is maximum.
— *Wave height* is calculated as two times the linear long term response divided by the transfer function value for the above wave period and wave direction.

The design sea state may also be established using a procedure similar of better to the design wave approach.

10.8.4 Design load cases

Non-linear wave load analyses are to be carried out for the design sea states.

A design load case is defined as a consistent load set, i.e. the external sea pressure is in balance with the inertia loads on the global FE model. This ensured that the FE model is well balance and that the reaction forces in the position for boundary conditions are minimized.

The design load cases are extracted as snap shots from the time series of the hull girder loads.

The design load case for the vertical bending moment at the reference positions is straight forward to determine by extracting the loads at the time corresponding to the maximum vertical bending moment for the selected reference position.

It is not straight forward how to extract design load cases for the torsion moment cases. The time instant corresponding to the maximum torsion moment will not necessarily give the highest stresses in the structure and the largest hatch cover deflection. It is therefore recommended to extract several design load case (i.e. snap shots) covering the complete oscillation cycle for the torsion moment and the horizontal bending moment.

10.8.5 Verification of structural loads

The hull girder loads (forces and bending moment) distributions obtained by stress integration of the FE model should be compared with those forces and moments from the wave load analysis. A difference of 5% is usually accepted.

Comparisons of these results are done to verify a correct load transfer.

10.8.6 Comparison of hull girder loads with Rules for Classification of Ships

The maximum hull girder loads according to the direct wave load analysis should be compared with those of the Rules for Classification of Ships.

The simultaneous values for the torsion moment, vertical bending moment and the horizontal bending moment should be compared with those of the Rules for Classification of Ships.

Care should be taken in selection of the critical load combinations. To evaluate the strength of deck and coaming structures, the wave torsion cases should be added to the still water hogging moment. To evaluate the bilge longitudinals, the wave torsion cases should be combined with the still water sagging moment.

10.9 Fatigue analysis (FLS)

The fatigue analysis should follow a procedure described as the full stochastic fatigue approach or a component stochastic procedure.

A linear wave load analysis can be used as basis for the fatigue analysis.

In case of a full stochastic fatigue analysis, the sea pressure and accelerations (inertia loads) for unit wave amplitude should be transferred to the structure for wave directions and wave periods as recommended earlier in this chapter.

The phase difference between the pressure at different locations and the acceleration in six degrees of freedom should be accounted for. This can efficiently be done by representing the pressure and the accelerations as complex number.

The full stochastic fatigue analysis involves a large amount of data requiring a fully automatic load transfer procedure. As an example with 20 wave periods and 12 wave directions, $20 \times 12 \times 2 = 480$ load cases (complex) assuming 2 loading condition.

11. Stress Combination

11.1 General

This chapter includes how to combine the stresses calculated based on a global FE model into total stresses.

11.2 Global FE stress based on Rule loads

In case only the Rule loads are applied to the global FE model, the stress combination should be according to Table 11-1.

Table 11-1 Stress combination using Rule loads

Case	*Stress components*			
	VSWBM	*VWBM*	*HWBM*	*TOR*
Case 1	100%	100%		
Case 2	100%	45%	100%	100% of σ_{MWT1}
Case 3	100%	45%	100%	100% of σ_{MWT2}

Note:

VSWBM: Vertical still water bending stress
VWBM: Vertical wave bending stress
HWBM: Horizontal wave bending stress
TOR: Torsion stress (still water and wave torsion)

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For details of stress components, see explanation given in section 6.3.

11.3 Global FE stress based on direct calculated wave loads

In case the loads are based on direct wave load analysis but applied to the structure in a simplistic manner as described in section 8, the stress combination should be according Table 11-2

Table 11-2 Stress combination for direct calculated wave loads and simplified load application

Case	*Stress components*				
	VSWBM	*VWBM*	*HWBM*	*TOR*	*Remark*
Wcase 1	Max	Max	Non	Non	
Wcase 2	Min	Min	Non	Non	
Wcase 3	Max	Corres.	Corres.	Max(A)	
Wcase 4	Max	Corres.	Corres.	Max(M)	
Wcase 5	Max	Corres	Corres	Max(F)	

Note:

Wcase: Wave load analysis case
Corres.: Corresponding load with maximised torsion
Max(A): Maximised Torsion at after part
Max(M): Maximised Torsion amidships
Max(F): Maximised Torsion at forward part

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The vertical and horizontal bending moment corresponding to the maximised torsion can be extracted from a non-linear time domain wave loads. The simultaneous vertical bending moment and horizontal bending moment at the time instant for the maximum torsion moment is then used. See section 10.8.4 for more details.

11.4 Stress based on direct wave load and direct load application

The loads are applied to the FE model as design load cases (see section 10.8.4) when a direct wave load analysis and load application have been carried out. These loads are simultaneously occurring loads and no stress combination is necessary.

12. Allowable Stress and Strength Criteria

12.1 General

This section presents criteria used for the different type of stress and strength analysis.

12.2 Allowable stresses when using Rule loads or simplified load application of direct calculated wave loads

The below allowable stress criteria should be used when the hull girder loads are based on:

— rule hull girder loads
— direct wave load calculation but simplified load application according to section 8.

The stresses should be:

— *Normal stress*: 175 f_1 [N/mm^2] for upright condition where only hull girder vertical bending stress components are considered.
— *Normal stress*: 195 f_1 [N/mm^2] for combined loading condition where all stress components except stresses due to warping deformations are considered together.
— *Normal stress*: 225 f_1 [N/mm^2], deck and hatch coaming structure, for combined loading condition where all stress components including stresses due to warping deformations are considered together.
— *Shear stress*: 100 f_1 [N/mm^2]
— *Equivalent stress*: 200 f_1 [N/mm^2]

12.3 Nominal stress when using direct wave load application

The allowable nominal stresses as explained in this section should only be used when loads are based on direct wave load analysis that are applied as sea pressure and inertial loads on the FE model.

Allowable stress criteria of the global analysis are as outlined below, but the stresses have to be finally assessed considering the local structural design, location, element fineness, etc.

Criteria for nominal stress:

— Equivalent stress of longitudinal members:

  — 0.9 σ_f [N/mm^2] if interaction between hatch cover and main hull structure is not included in stress calculation
  — 0.95 σ_f [N/mm^2] if interaction between hatch cover and main hull structure is included in stress calculation

— Equivalent stress of the flange in transverse material:

  — 0.85 σ_f [N/mm^2]

σ_f = minimum upper yield stress of the material

Table 12-1 Material factor, f_1

Material	*Yield strength [N/mm^2]*	*Material factor, f_1*
Mild Steel	235	1.00
HT32	315	1.28
HT36	355	1.39
HT40	390	1.47[1)]

1) If relevant fatigue assessment is carried out, material factor for HT40 steel may be increased to maximum 1.51.

12.4 Peak stress in way of hatch corners

When loads are based on 20 year North Atlantic operation (i.e. Rule loads or direct wave loads), the allowable local peak stresses (equivalent stress) in the hatch corners may be taken as:

σ_e = 400 f_1 [N/mm^2]

12.5 Buckling strength

The ultimate buckling strength is checked for compliance with the Rules for Classification of Ships Pt.3 Ch.1 Sec.13 irrespective of whether loads based on the Rules of direct wave loads analysis.

13. Hatch Corner Analysis

13.1 Objective

The objectives of the analysis are to examine the stress response including stress concentration of the structural details and to provide the detailed stress information for fatigue assessments.

13.2 Analysis model

a) In general, it is recommended to carry out a fine mesh analysis for the hatch corner structures in way of engine room front bulkhead, amidships part and fore part of cargo hold area. The selection of hatch corners in the midship region shall be made based on the level of stresses from the global analysis.

b) The analysis model in the midship region will extend two web spaces aft and forward of transverse bulkhead location in the longitudinal direction, and from the hatch coaming top to 2nd deck level vertically. The model will include both port and starboard side to account for asymmetric load by torsion.

c) If the scantlings and or structural arrangement differ between the watertight bulkhead and the support bulkhead, due consideration will be necessary, i.e. separate modelling may be required.

d) The analysis model of the engine room front bulkhead will extend two web spaces aft and forward of transverse bulkhead location in the longitudinal direction and downward to 2nd deck level vertically. The model will also extend up to the suitable level of deckhouse deck, if applicable.

e) If the ship has the engine room located at a position forward of the normal position, the global analysis may result in relatively high stresses in the hatch corners located aft of the engine area. A separate fine mesh analysis will then be required for such area.

f) Mesh arrangement in way of hatch corner area is important. It is recommended that the radius is to be divided into 8 to 10 divisions, but with an element size of maximum 2t (i.e. twice the plate thickness).

g) It is recommended to utilise fictitious truss elements along the edge of hatch corner radius for easy stress check.

h) All the models are to include fine mesh in way of hatch corners as well as at the scarphing and at the end terminations of longitudinal hatch coamings where relevant.

i) The coaming stays shall also be properly represented in the model by shell or membrane elements.

j) All cut outs, e.g. ventilation opening, access openings, shall be included in the model.

k) Secondary stiffeners may be represented by truss elements unless their contribution to the stresses, at the area of concern, is negligible.

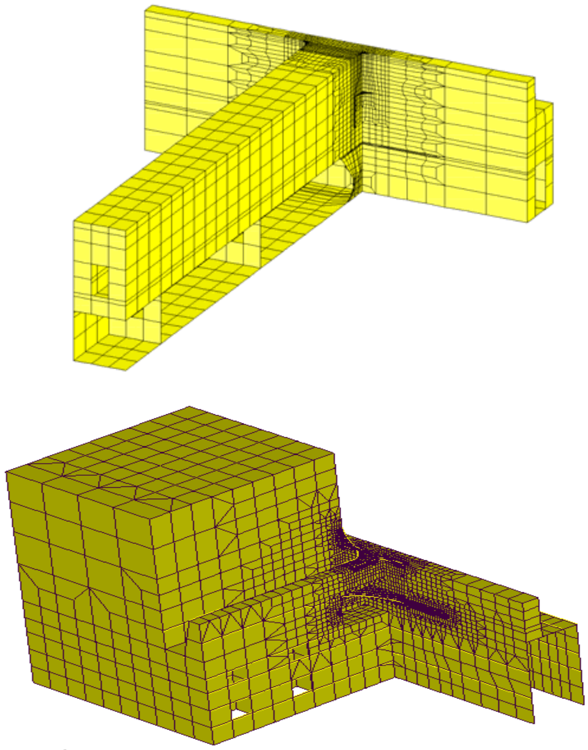

Figure 13-1
3-D views of hatch corner models (midship and engine room area)

13.3 Load application

The load cases applied to the local model should be the same as for the global model.

The deformation obtained from the global analysis will be applied to the relevant nodes as forced deformations.

Local loads, e.g. container load and sea loads shall be applied on the local model as found relevant.

14. Hot Spot Stress Evaluation in way of Hatch Corners

14.1 General

This chapter includes stress concentration factors to be used for peak stress analysis of hatch corners. The stress concentration factors are to be multiplied by the nominal stress in relevant position. The nominal stress may be found from a Rule torsion analysis (see section 6) or from a direct nominal stress analysis modelling the complete hull as described in section 7 with relevant loads (see section 10).

Hot spot stresses are used to compare with relevant acceptance criteria in case of extreme hull girder loads or with acceptable dynamic stresses at suitable probability level in case of fatigue.

14.2 Background and application

In way of the hatch corner structure in a container ship, stress concentration factor (K factor) varies along the edge of the hatch corners depending upon stress component, i.e vertical bending, horizontal bending, warping stress and stress due to warping deformation.

In order to calculate the hot spot stresses reasonably accurately along the edge of hatch corners, the variations of stress concentration shall be taken into account for each stress component and the nominal stress component shall be considered with those variations.

The following generalised stress concentration factor for the hatch corners in the midship area and engine room bulkhead was established based on parametric investigation over different hatch corner designs.

Hot spot stress can be calculated by multiplying the nominal stress by the corresponding K-factor that varies along the edge of the hatch corner.

The followings may in general be applicable to hot spot stress calculation in way of hatch corner edges if the hot spot stress is not calculated by a hatch corner fine mesh analysis model.

The stress concentration factors proposed in the following tables are basically set for normal hatchway arrangement and hatch corner designs, e.g. radius type in the midship area and key hole type in the engine room bulkhead.

If the hatch corners do not comply with the hatch corner radius requirement in the Rules for Classification of Ships Pt.5 Ch.2 Sec.6 B.205-207, due consideration may be necessary to use the stress concentration factor for peak stress calculation.

All stress components, vertical bending stress, horizontal bending stress and torsion stress, shall be considered separately because their variations differs along the edge of hatch corner.

The hatch corner edges are assumed free from weld, eccentricity and misalignment. Thus only the stress concentration due to the geometry effect are considered in K-factor tables.

The K-factor tables were established through parametric study using fine mesh (about 1.5t mesh arrangement) models with fictitious truss elements along the edges.

The K-factors were obtained as defined in the Fatigue Classification Note 30.7, by use of the simple equation

$$K = \frac{\sigma_{hot\ spot}}{\sigma_{nominal}}$$

In these cases, $\sigma_{\mathrm{nominal}}$ is defined as in the Fatigue Classification Note 30.7 Appendix D.

For the stress concentration factor of the torsion (warping) deformation case, shear force effect was also included in the stress concentration factor.

The additional local strengthening is the normal practice for hatch corner plates and transverse box beam ends in most cases. The strengthening by thicker plating at the hatch corner area reduces the actual peak stress at the hatch corner edges and this condition shall be considered when calculating the nominal stress at the end part of the transverse box beam.

To provide relevant nominal stress at the end of the transverse box beam structures for the torsion (warping) deformation case, the mean stress of these two stress values, i.e. the stress with the general scantlings and the reduced stress due to local strengthening in the end, is to be used as the nominal stress for the end of the transverse box beam as shown in Figure 14-1.

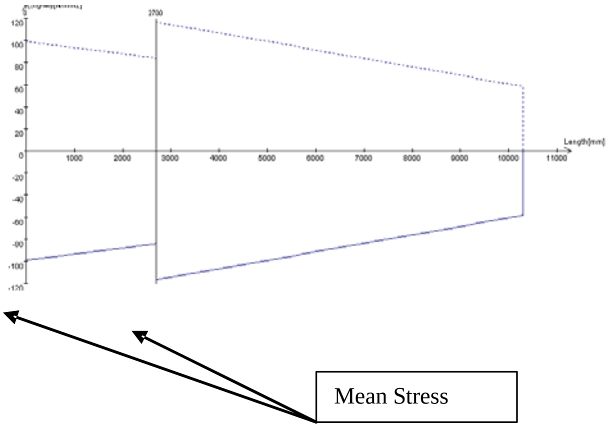

Figure 14-1
Nominal stress distribution at end of transverse box beam

14.3 Hatch corners in midship area

The radius part of the hatch corner edge is divided into 10 segments and the corresponding K-factors are presented for each stress component in the following tables.

The segments are numbered along the hatch corner edge from the longitudinal upper deck (longitudinal hatch coaming top plate) to the upper deck transverse (transverse hatch coaming top plate), as shown in Figure 14-2.

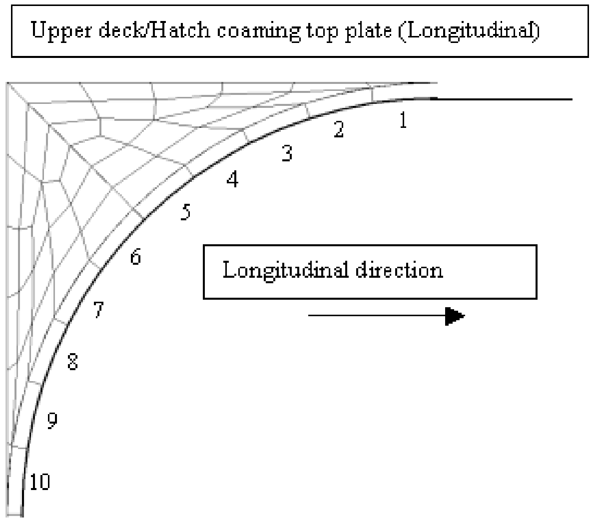

Figure 14-2
Segment numbering along hatch corner edge (midship area)

The following tables can be used for hot spot stress calculation based on the nominal stresses.

To determine the hot spot stress of the hatch corners, each nominal stress component shall be multiplied with the corresponding stress concentration factors for all segments along the hatch corner edge.

Table 14-1 Stress concentration factor for vertical bending stress (Kv) and warping stress (Kwt)

Seg. No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Upper Deck	1.34	1.58	1.72	1.64	1.37	1.0	0.61	0.26	0	0
Coam. Top	1.69	1.88	1.88	1.63	1.21	0.72	0.27	0	0	0

Table 14-2 Stress concentration factor for horizontal bending stress (Kh)

Seg. No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Upper Deck	1.13	1.34	1.48	1.42	1.20	0.90	0.57	0.27	0.05	0
Coam. Top	1.33	1.48	1.47	1.27	0.92	0.53	0.17	0	0	0

Table 14-3 Stress concentration factor for warping deformation (Kgt)

Seg. No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Upper Deck	0.52	0.91	1.58	2.27	2.78	3.10	3.11	2.91	2.46	1.94
Coam. Top	0.84	1.10	1.37	1.55	1.62	1.59	1.49	1.31	1.08	0.84

14.4 Hatch corner in way of engine room bulkhead

The stress concentration factors of the hatch corner in way of the engine room bulkhead differ from the hatch corners in the midship area mainly due to the different shape of the hatch corner design.

The key hole type design is normal for the hatch corner design. Thus, the stress concentration factors have been proposed for the key hole type design.

The same procedure as for the midship area can be used to determine the hot spot stress for all relevant stress components, but the stress component by warping deformation can be omitted since relative deflection at the engine room bulkhead is too small to be considered.

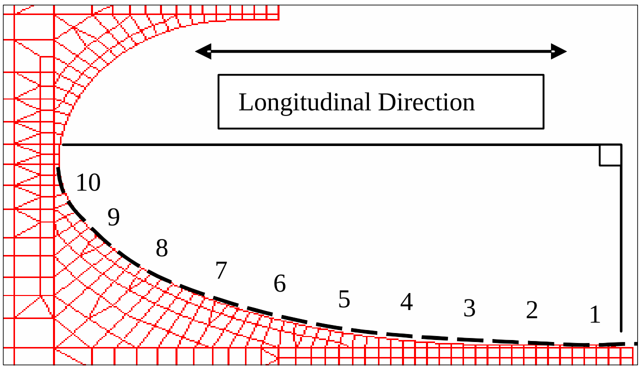

Figure 14-3
Segment numbering along hatch corner edge (Engine room bulkhead)

The radius (streamlined) part of the hatch corner edge is divided into 10 segments and the corresponding K-factors are presented for each stress component in the following tables.

The segments are numbered along the hatch corner edge from the longitudinal upper deck (longitudinal hatch coaming top plate) to the upper deck transverse (transverse hatch coaming top plate), as shown in Figure 14-3.

Table 14-4 Stress concentration factor for vertical bending stress (Kv)

Seg. No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Upper Deck	1.0	1.07	1.15	1.20	1.32	1.40	1.36	1.24	0.98	0.47
Coam. Top	1.69	1.88	1.88	1.63	1.21	0.72	0.27	0	0	0

Table 14-5 Stress concentration factor for horizontal bending Stress (Kh)

Seg. No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Upper Deck	1.0	1.08	1.07	1.23	1.38	1.49	1.51	1.40	1.1	0.27
Coam. Top	1.33	1.48	1.47	1.27	0.92	0.53	0.17	0	0	0

Table 14-6 Stress concentration factor for warping stress (Kwt)

Seg. No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Upper Deck	1.0	1.10	1.2	1.32	1.59	1.83	1.89	1.94	1.82	1.13
Coam. Top	1.69	1.88	1.88	1.63	1.21	0.72	0.27	0	0	0

15. Simplified Fatigue Assessment

15.1 Longitudinal connections

For container ships of length less than 190 m, without the **NAUTICUS(Newbuilding)** notation:

— Fatigue assessment for side shell longitudinal connections may be carried out by Section Scantlings in accordance with the Rules for Classification of Ships Pt.3 Ch.1 Sec.7 E 400 Fatigue control of longitudinals, main frames and tween-deck frames.

— Additionally, all longitudinal connections can be checked according to the procedure found in Classification Notes 30.7 “Fatigue Assessment of Ship Structures” and corresponding to the Rules for Classification of Ships Pt.3 Ch.1 Sec.17 Fatigue Control.

For container ships of length greater than 190 m, and for ships of length less than 190 m with the **NAUTICUS(Newbuilding)** notation:

— All longitudinal connections to be checked in accordance with the Rules for Classification of Ships Pt.3 Ch.1 Sec.16, and procedures found in Classification Note 30.7 “Fatigue Assessment of Ship Structures”.

15.2 Hatch corners

15.2.1 Combined nominal stress calculation

The combined nominal longitudinal stress, σ_g, due to horizontal and vertical hull girder bending and torsion may in general be determined in accordance with “section 9.3 Simplified Calculation of the Combined Longitudinal Stress in Ships with Large Hatch Openings” in Classification Note 30.7 Fatigue Assessment of Ship Structures.

The stress concentration factors can be taken as shown in section 14.

According to the procedures described in the Classification Notes 30.7, the total combined stress range $\Delta\sigma_g$ can be predicted as:

$$\Delta\sigma_g = 2\,|\,\sigma_h + \sigma_{wt} + \sigma_{gt} + 0.45\sigma_v\,|$$

σ_h = horizontal wave bending stress from horizontal wave bending moment at 10^{-4} probability level.

σ_{wt} = warping stress at the position considered. This can be calculated as described in section 9.3 of the above mentioned Classification Note or it can be calculated using the DNV software Section Scantling applying torsion at 10^{-4} probability level.

σ_{gt} = bending stress of (upper) deck structure due to warping deflection of hatch openings. This stress component may be calculated by 3-D beam using forced deflections (output from Section Scantling) as input. See section 6.3.4 for further description.

σ_v = vertical wave bending stress for vertical wave bending moment at 10^{-4} probability level.

Note:

The stress σ_h is similar as σ_{WH} (see section 6.3) but at 10^{-4} probability level. Further; σ_{wt} is similar to σ_{WT}, σ_{gt} is similar to σ_{bww} and σ_v is similar to σ_W but at 10^{-4} probability level (instead of 20 year return period in North Atlantic).

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15.3 Stress concentration factors (K-factors)

Stress concentration factors for all stress components can be found in section 14.

15.3.1 Fatigue life calculations

The combined longitudinal hot spot stress range, $\Delta\sigma_g$(hot spot), including all stress components may be determined according to the formulae as below for both port and starboard side.

Port side:

$\Delta\sigma_g(\text{hot spot}) = 2\,|\,Kwt \cdot \sigma_{wt} + Kgt \cdot \sigma_{gt} + 0.45 \cdot Kv \cdot \sigma_v\,|$

Starboard Side:

$\Delta\sigma_g(\text{hot spot}) = 2\,|\,Kh \cdot \sigma_h + Kgt \cdot \sigma_{gt} + 0.45 \cdot Kv \cdot \sigma_v\,|$

Note:

Horizontal bending stress (σ_h) and torsion stress (σ_{wt}) will in general have opposite signs in the midship region. This means that one of the two stress components will reduce the total stress range. However, to be conservative, the stresses are added with positive sign.

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Based on this, the fatigue damage; Dp and Ds, for the port and starboard hatch corners are to be calculated separately in accordance with section 2.1.2 of the Classification Note 30.7 on fatigue with the following assumptions:

Assumptions:

1) Weibull shape parameter $h = h_0 = 2.21 - 0.54 \cdot \log(L)$
2) S-N curve parameters will be selected for curve III (Base material in air)
3) The fraction of the design life time at sea: 0.85
4) For hatch corners kept free from welding, protected against corrosion and smoothly grinded, the fatigue life can be multiplied by a factor 2 (Classification Note 30.7 section 2.3.6)

Finally, the total fatigue damage is obtained as the average of the port and starboard damage.

16. Comprehensive Fatigue Assessment

The comprehensive fatigue analysis (full stochastic fatigue) is based on the direct wave load computation and finite element analysis for stress determination. A flow diagram of the procedure is shown in Figure 16-1.

16.1 General

The fatigue procedure follows the direct analysis in the DNV Classification Note 30.7 “Fatigue Assessment of Ship Structures”.

The calculations are based on environmental data for World-Wide trade, and an equal probability of all wave headings is assumed. The fatigue criterion is 20 years in World-Wide trade.

The fatigue analyses shall at least be carried out for three selected hatch corners and the typical longitudinal connection in side shell amidships. Different approaches can be followed, depending on the structural detail.

A complete overview of the different fatigue load calculation methods is given in Classification Note 30.7, Ch.5. Relevant methods for a Level 4 analysis are applying a stress component based stochastic analysis (CN 30.7, section 5.6) or a fully stochastic analysis (CN 30.7, section 5.7).

16.2 Longitudinals in the bilge and side shell in midship region

The fatigue lives of the midship longitudinals can be calculated by a fully stochastic analysis.

A fully stochastic analysis as described in Classification Note 30.7, section 5.7, covers these effects. It is recommended to use fine mesh models as sub-models in the global FE-model.

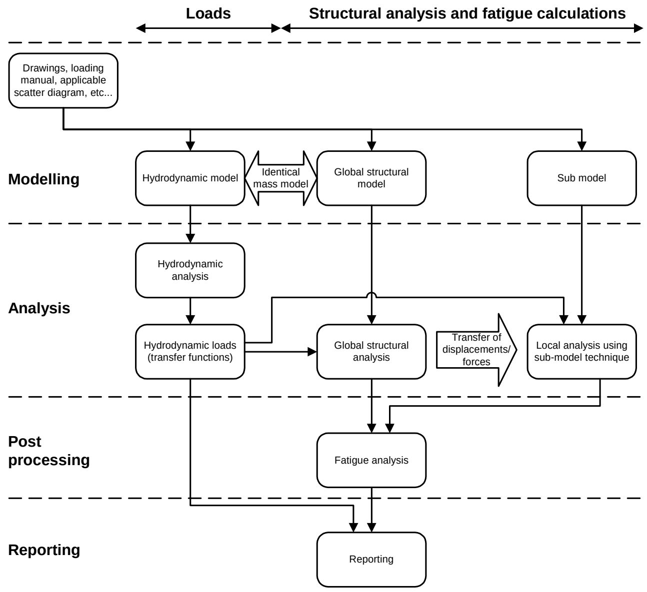

Figure 16-1
Direct full stochastic fatigue analysis flowchart

16.3 Hatch corners

Examples, of fine mesh models (sub-models) are shown in Figure 13-1. Hatch corner models are used for the fatigue analysis too.

The deformation results from the global analysis are transferred to the local models as forced deformations. The idea of sub-modelling is in general that a particular portion of a global model is separated from the rest of the structure, re-meshed and analysed in more detail.

The calculated deformations from the global analysis are applied as boundary conditions on the borders of the sub-models, represented by cuts through the global model. The appropriate boundary solutions are determined and applied to the sub-models.

16.3.1 General assumptions

The following assumptions are normally the basis for fatigue assessment of the hatch corners

- Fatigue damage shall be calculated on basis of the Palmgrens-Miner rule, assuming linear cumulative damage.
- The wave load analysis should be carried out according to the procedure described in section 10.
- The target life is normally 20 years
- The S-N Curve III (Base material, Air or Cathodic protection) shall be used for the fatigue calculations, i.e. effective corrosion protection can be assumed for the entire lifetime of the vessel.
- The fraction of time at sea shall be taken as 0.85.
- In general, no reduction for mean stress effect may be included since the tensile mean stress is always in all loading conditions for the details evaluated. If stress pattern is changed due to different loading pattern, then mean stress effect can be considered.

16.3.2 Cumulative damage

The fatigue damage shall be calculated on basis of the Palmgrens-Miner rule, assuming linear cumulative damage. The damage shall be calculated on basis of summation of damage from each short term distribution in the scatter diagram (i.e. a Rayleigh approach).

Alternatively, the fatigue damage can be based on a Weibull fitness of the long term stress distribution and a bi-linear (i.e. two-slope) S-N curve.

The relevant fatigue damage expression can be found in Classification Note 30.7 section 13. Appendix D - Two-Slope S-N Curve Fatigue Damage Expression.

16.4 Structures exposed to mainly dynamic loads

Some structure in the cargo hold area is mainly exposed to dynamic loads. This means that fatigue can become critical.

For vessels were the analysis scope includes extensive direct strength assessment, it is recommended to carry out a simplified fatigue assessment also including transverse webs, hatch coaming stays and support bulkheads. Such structures are exposed to dynamic loading induced by sea pressure and container cargo in roll and pitch motions could be carried out.

The additional fatigue assessment may be carried out by using the cargo hold analysis model (see section 5) for additional loading conditions containing dynamic loads only. The load cases are similar as LC3-LC5 in section 5.5 but were only the dynamic part of the sea pressure is modelled. This means:

p = 6,7 y tan (ϕ/2) Zs [kN/m^2]
  = 0.0 minimum on submerged side
  = Ze, but not less than - 10 y tan (ϕ/2) [kN/m^2] on emerged side
Zs = 10 (Z - T_A), minimum = 0.0 : on submerged side
Ze = 10 (Z - T_A), maximum = 0.0 : on emerged side
y = transverse distance in m from centre line to considered position
T_A = actual considered draught in m
z = vertical distance in m from base line to considered position
ϕ = as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.4 B.

The accelerations are modelled similar as for the load case LC3-LC5. The allowable stress should be according to Table 16-1.

Table 16-1 Allowable stresses of primary members for additional load cases

Structures/ Load cases	*Nominal stress, σ [N/mm^2]*	*Shear stress, τ [N/mm^2]*		*Equivalent stress, σ_e [N/mm^2]*
		One plate flange	*Two plate flange*	
Hatch coaming stays, support bulkhead, etc.	100 f_1 for dry area 85 f_1 for corrosive area	60 f_1		

17. References

1) Det Norske Veritas, Rules for Classification of Ships, Høvik.

2) Det Norske Veritas, Classification Note 30.7 Fatigue Assessment of Ship Structure, Høvik.

3) Det Norske Veritas, Classification Note no. 31.1 Strength Analysis of Hull Structure in Bulk Carriers, Høvik.

18. Appendices concerning design procedure of various structural members

App. A: Lashing Bridge Structure

App. B: Hatch Cover Stoppers

App. C: Hatch Cover Guide Post

App. D: Hatch Covers

App. E: Fuel Oil Deep Tank Structure

Appendix A
Structural Verification Procedure for Lashing Bridge Structure

A.1 Introduction

A.1.1 Post-panamax containerships are normally equipped with lashing bridges in order to simplify the securing of high stacks and large number of cargo containers on hatch covers/ deck space.

A.1.2 Design loads from the container securing equipment acting on the lashing bridge are described in the Rules for Classification of Ships Pt.5 Ch.2 Sec.6 G700.

A.1.3 Forces in container securing equipment and the working load of the securing device are to be less than half the breaking load of the item. In this regard, half the breaking load of the lashing bar (safe working load) is a theoretical maximum load to be taken by the lashing bridge for strength verification.

A.1.4 This simple force definition is suitable for the verification of local strength of items like lashing eyes and their welding connection, etc. It seems to be a too conservative approach to apply half the breaking load for all lashing bars connected to the lashing bridge simultaneously. The more lashing bars applied to distribute lashing forces, the higher total load will be applied to the lashing bridge.

A.1.5 In order to have a more realistic force application, the following procedure is recommended for lashing bridge design.

A.2 Assumption

A.2.1 Total container stack weight shall be assumed evenly distributed to the container in the stack, i.e. homogeneous weight distribution. However, container lashing arrangement will be taken as per the actual lashing arrangement scheme in the container lashing manual.

A.2.2 Lashing force will be calculated for the lashing bars securing the stack to the lashing bridge, and the lashing force shall be applied to the lashing bridge at the lashing eye locations.

A.2.3 Relative displacement between hatch cover and hull structure is to be considered as given in DNV rule Pt.3 Ch.3 Sec.6 F203. However this will in normal cases be covered by applying case 4 described in section 3.3.4.

A.3 Loading conditions

A.3.1 Accelerations

Accelerations (a_t and a_l) are to be calculated as given in Rule Pt.3 Ch.1 Sec.4 B700 and 800.

For simplification, the accelerations may be calculated half height of the mid stack.

Longitudinal position of the lashing bridge is also to be considered to get proper acceleration factors.

A.3.2 Lashing force calculation to lashing bridge

Lashing force for container stack is to be calculated for maximum container stack weight based on homogeneous weight distribution. The actual container weight distribution, that is normally for 40 feet container stack should not be used.

A.3.3 Load cases

A.3.3.1 Case 1

Lashing force for simultaneous loading in fore and aft space: Lashing forces are to be applied to fore and aft part of the lashing bridge in line with the connected lashing bars along the same direction.

For simple application, the lashing force can be decomposed into force components in longitudinal, transverse and vertical direction.

A.3.3.2 Case 2

Lashing force for container loading in fore space only.

A.3.3.3 Case 3

Lashing force for container loading in aft space only.

A.3.3.4 Case 4

Lashing force for container loading in fore space only: Safety working load (250 kN) is to be applied to short lashing bars and half the safety working load (125kN) is to be applied to long lashing bars. This case will cover the relative displacement between hatch covers and main hull structures, i.e. lashing bridge.

A.4 Allowable stress

— Normal stress : $\sigma = 210\ f_1$ [N/mm^2]
— Shear stress : $\tau = 120\ f_1$ [N/mm^2]

Note:

The stresses are allowable nominal stress. If fine mesh analysis is carried out, then the mean stress of the area may be compared to the mentioned allowable stress.

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Appendix B
Structural Verification Procedure for Hatch Cover Stoppers

B.1 Introduction

B.1.1 Hatch cover stoppers can either be rolling stoppers which are fixations against transverse movement (one way fix for longitudinal shifting) or rolling/ pitching stoppers (pin stopper) which are fixations against movement in both directions.

B.1.2 To prevent damage to the hatch covers and ship structures, the location and type of stoppers is to be harmonised with the relative movements between the hatch covers and ship structure.

B.1.3 The number of stoppers is to be as small as possible, preferably only one stopper at each end of the hatch cover panel.

B.1.4 A common arrangement for hatch covers, are one rolling stopper at one end and rolling/pitching rolling stopper (pin stopper) at the other end.

B.2 Assumption

B.2.1 If the container stack is attached/secured to other structures (i.e. lashing bridge) than the hatch cover, the horizontal force on hatch cover may be reduced. However, to be conservative, this may not be considered in the force calculation.

B.2.2 Friction force at bearing pads may reduce the horizontal force by about 10% as given the Rules for Classification of Ships Pt.3 Ch.3 Sec.6 F601. However this shall be decided based on bearing pad material. If bearing pad is of low friction material, it is recommended not to reduce the horizontal forces.

B.2.3 Hatch coaming and supporting structures are to be adequately stiffened to accommodate the loading from hatch covers.

B.2.4 Relative displacement between hatch cover and hull structure is to be considered as given in DNV rule Pt.3 Ch.3 Sec.6 F203 in connection with the strength of stopper. However this may in the normal case be covered by applying longitudinal force to the pin stopper.

B.3 Loading conditions

B.3.1 Accelerations

Accelerations (a_t and a_l) are to be calculated as given in Rule Pt.3 Ch.1 Sec.4 B700 and 800. Transverse acceleration (a_t) is to be calculated as specified in Rule Pt.3 Ch.1 Sec.4 B or Pt.5 Ch.2 Sec.6 G301. The bigger of the extreme dynamic loads or the minimum value is to be used.

The accelerations will be calculated for a level corresponding to the half height of the mid stack.

B.3.2 Force application

All container loads and hatch cover weight are to be considered in the horizontal force calculation.

Total container weight is normally maximum for 20 ft container stack loading.

The horizontal force is to be applied to the level of the highest contact point between the hatch cover and the rolling stopper.

For pin stopper, the force is to be applied to the middle of the contact area.

B.3.3 Load cases

B.3.3.1 Case 1 (Transverse force)

Pt (total) = 0.67 a_t · (Total no. for 20 ft container stacks · Weight (tons)+ Hatch cover weight(tons)) [kN]

Horizontal force will be taken by two stoppers at both ends of the hatch cover and thus half of Pt is to be applied to each stopper.

B.3.3.2 Case 2 (Longitudinal force)

Pl (total) = 0.67 a_l · (Total no. for 20 ft container stacks · weight (tons)+ Hatch cover weight(tons)) [kN]

Pin stopper will take the whole force.

B.4 Allowable stress

— Normal stress : σ = 120 f_1 [N/mm^2]
— Shear stress : τ = 80 f_1 [N/mm^2]
— Equivalent stress : σ_e = 150 f_1 [N/mm^2]

Appendix C
Structural Verification Procedure for Hatch Cover Guide Post

In case of deleting anti-lifting devices of non-weather-tight hatch covers.

C.1 Introduction

C.1.1 Hatch cover on deck can be non-weather-tight and weather-tight hatch covers.

C.1.2 Securing devices (i.e. anti-lifting device) that locks the hatch cover to the main hull structure are fitted to the hatch covers to maintain integrity during extreme conditions.

C.1.3 The anti-lifting device shall be fitted for non-weather-tight hatch covers.

C.1.4 In case there are not lashing bridge, it is recommended to keep anti-lifting device as per normal requirement also for non-weather-tight hatch covers.

C.1.5 If the lashing bridges are arranged and the anti-lifting devices are omitted, the following evaluation procedure is recommended to ensure the structural integrity in extreme condition.

C.1.6 In general, there are two guideposts for each panel of hatch cover, one at fore and aft end. This procedure is aimed at providing the required minimum strength of the guide post in way of deleting the anti-lifting device.

C.2 Assumptions

C.2.1 The lashing bars are to secure the container stacks on the hatch cover firmly to the lashing bridge. The cargo securing calculation shall be done according to DNV requirement.

C.2.2 When the vessel is listed, the transverse force due to the on-deck containers can be taken by lashing bars, bearing pads through friction and hatch cover stoppers. However, for strength check, the total force is to be assumed to be taken by the hatch cover stoppers.

C.2.3 This means that the guidepost will never be exposed to horizontal force in operation unless all lashing bars are broken and coincidentally hatch covers are lifted up beyond the functioning level of the hatch cover stoppers.

C.2.4 Even without anti-lifting device, lifting-up of hatch covers is unlikely to occur even in extreme operation if the lashing is done properly. However, the strength of the guidepost shall be designed for a certain unrealistic condition in order to have safety redundancy in extreme conditions.

C.3 Loading cases

C.3.1 Acceleration

Transverse acceleration (a_t) is to be calculated as specified in Rule Pt.3 Ch.1 Sec.4 B or Pt.5 Ch.2 Sec.6 G301, i.e. whichever bigger of the extreme dynamic loads or the minimum value is to be used. The acceleration will be calculated at a vertical position corresponding to the mid stack height.

C.3.2 Forces application

All container load and hatch cover weight are to be considered in the transverse force calculation. Total container weight is normally maximum for 20 ft container stacks.

The transverse force is to be applied at a level corresponding to the half the hatch cover height or the highest contact point between the hatch cover and the guidepost, whichever is highest.

C.3.3 Load

Pt (total) = a_t · (Total no. for 20 ft container stacks · weight + Hatch cover weight) [kN]

This transverse force can be taken by two guideposts at fore and aft ends of hatch cover. Thus, half Pt is to be applied for strength check.

C.4 Allowable stresses

— Normal stress : $\sigma = 210\ f_1$ [N/mm^2]
— Shear stress : $\tau = 120\ f_1$ [N/mm^2]

Appendix D
Structural Verification Procedure for Hatch Covers

D.1 Introduction

D.1.1 Hatch cover structures consist of grillage system in way of container ships.

D.1.2 Hatch cover is mounted on the bearing pads which take vertical force, whilst the stoppers take transverse force.

D.2 Assumption

D.2.1 Total container stack weight shall be assumed evenly distributed to the container in the stack, i.e. homogeneous weight distribution.

D.2.2 V.C.G. of each container in the stack is 45% of the container height.

D.2.3 Although the container stack is secured to other structures than the hatch cover, for example lashing bridge, no effect is to be considered on force calculation

D.2.4 Hatch coaming and supporting structures are to be adequately stiffened to accommodate the loading from hatch covers.

D.2.5 Relative movements between hatch cover and hull structure is to be considered as given in DNV rule Pt.3 Ch.3 Sec.6 F203 in connection with the strength of stopper. However this may in the normal cases be covered by applying longitudinal force to the pin stopper.

D.3 Loading conditions

D.3.1 Accelerations

Accelerations (a_t and a_l) are to be calculated as given in Rule Pt.3 Ch.1 Sec.4 B700 and 800. Transverse acceleration (a_t) is to be calculated as specified in Rule Pt.3 Ch.1 Sec.4 B or Pt.5 Ch.2 Sec.6 G301. The bigger of the extreme dynamic loads or the minimum value is to be used.

In general, a homogeneous weight distribution of the container stack is recommended used. For stacks of homogeneous weight distribution, the accelerations will be calculated based on a Vertical Center of Gravity for the stack corresponding to a VCG of the individual containers of 45% of the container height.

D.3.2 Force application

All container loads and hatch cover weight are to be considered in the horizontal force calculation.

Total container weight is always maximum for 20 ft container stack loading in connection with hatch cover strength design. Total stack load will be split into 4 container corners. The following load cases will be limited to 20’ container loading.

D.3.3 Load cases

D.3.3.1 Case 1:

Full stacks and vertical acceleration in upright condition

Pv (stack) = ($g_0 + 0.5 \cdot a_v$) · (container stacks weight (tons)) [kN]

D.3.3.2 Case 2:

Full stacks and combined vertical with transverse acceleration:

Pv (stack) = g_0 · (container stacks weight(tons)) [kN]

Pt (stack) = 0.67 · *at* · (container stacks weight(tons)) [kN]

Pv (transverse) = ± Pt · H / Container width

H : A distance from the bottom of container stack to the vertical centre of gravity of the stack

D.3.3.3 Case 3:

One empty stack and vertical acceleration in upright condition:

This case will be similar to Case 1 except one full empty container stack abreast.

D.3.3.4 Case 4:

One empty stack and combined with vertical and transverse acceleration.

This case will be similar to Case 2 except one empty container stack abreast.

D.4 Allowable stress (Rules for Classification of Ships Pt.3 Ch.3 Sec.6 E700)

— Normal stress : $\sigma = 0.58 \cdot \sigma_f$ [N/mm^2]
— Shear stress : $\tau = 0.33 \cdot \sigma_f$ [N/mm^2]
— Shear buckling : $\tau = 0.87\ \tau_{cr}$

Due to the relatively thin and high web plates of the hatch cover girder system. The shear buckling criteria as per the Rules for Classification of Ships Pt.3. Ch.1 Sec.13 B300 needs to be considered.

— Plate Critical Buckling Stress
$\sigma_c \geq \sigma_a / 0.87$

Appendix E
Strength analysis for fuel oil deep tank structure in container hold

E.1 General

The objective of the strength analysis is to determine the scantling of primary structure of the fuel oil deep tanks arranged in container hold, i.e. fuel oil deep tanks located inboard of the inner skin, above the inner bottom, and between adjacent transverse bulkheads.

Strength analysis by use of finite element methods is mandatory for container ships with the **NAUTICUS(Newbuilding)** notation and shall be carried out in accordance with principles described in section 5.

E.2 Analysis Model

The analysis model shall extend from one 40 ft bay aft of the aftermost fuel oil tank bulkhead to one 40 ft bay forward of the foremost fuel oil tank bulkhead.

The model shall normally cover the full breadth of the ship in order to account for unsymmetrical load cases (Heeled or unsymmetrical tank test conditions).

In principle the actual shape of outer shell may be represented as it is. However, the simplification by using the shape of the midship section unchanged for the whole model length is acceptable if due consideration is given to the stress evaluation of the changed structure.

Modelling of geometry, element and mesh size are given in Chapter 5.3.

E.3 Boundary Conditions

Selection of boundary conditions and calculation of spring constant are given in section 5.4.

E.4 Design Load

Design container forces are given in section 3.3.

Design liquid pressures in tank are given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.4 C302 [5] and Pt.3 Ch.1 Sec.12 B310, and the density of fuel oil used in the calculation shall in general not be less than 1.025 t/m^3.

In case the actual overflow height is used to define the internal pressure head for the tank test conditions, the allowable stress is subject to special consideration.

The sea pressures in upright conditions and tank test conditions are given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.4 C200.

In heeled conditions, the sea pressures are normally to be taken as:

$$P = 10\,(T_A - z) + 6.7\,y\tan(\phi/2) \quad [\mathrm{kN/m^2}]$$

on submerged side and

$$P = 10\,(T_A - z) + 10\,y\tan(\phi/2) \quad [\mathrm{kN/m^2}]$$

on emerged side

= 0 minimum
T_A = actual considered draught in m
z = vertical distance in m from base line to considered position
y = transverse distance in m from centre line to considered position
ϕ = as given in the Rules for Classification of Ships Pt.3 Ch.1 Sec.4 B

E.5 Load Cases

The load cases as described in the text below are to be examined. The container load above fuel oil tanks, on hatches above container holds, aft bay and fore bay may in general be for 40 ft container stacks.

For two(2) F.O. tanks with one(1) longitudinal bulkhead arranged in container hold, the load cases of LC-4F and LC-6F are to be omitted.

For one(1) F.O. tank with no longitudinal bulkhead, four(4) F.O. tanks with three(3) longitudinal bulkheads, or for arrangements where more F.O. tanks are arranged in container hold, the load cases to be specially considered.

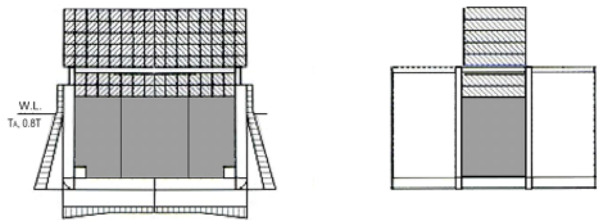
E.5.1 Full F.O. tanks at reduced draught (LC-1F)

All F.O. tanks are to be full, and cargo mass above F.O. tanks top in hold and on deck in seagoing upright condition at reduced draught.

In case F.O. tank top is arranged below the 2nd deck level, the maximum cargo mass is to be applied in order to check supporting structures of F.O. tank top. 20 ft or40 ft containers to be applied as relevant.

The adjacent holds and decks are to be assumed empty.

The reduced draught is in general to be actual draught as describe in Trim & Stability Booklet. May be taken as 0.8T, if not known.

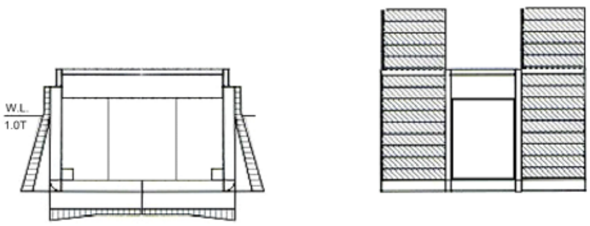


Load Case 1

E.5.2 Empty F.O. tanks at scantling draught (LC-2F)

All F.O. tanks are to be empty, and the container space above F.O. tanks top in hold and on deck are to be empty.

Cargo mass adjacent in holds and decks in sea going upright condition at scantling draught.



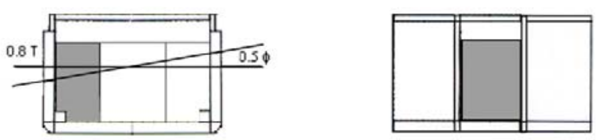
Load Case 2

E.5.3 Heeled condition, side tank full (LC-3F)

One(1) side F.O. tank is to be full in heeled condition at reduced draught.

The adjacent holds and decks are to be assumed empty.

The reduced draught is generally not to be considered larger than 0.8T.



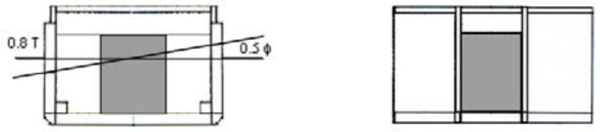
Load Case 3

E.5.4 Heeled condition, centre tank full (LC-4F)

One(1) centre F.O. tank is to be full in heeled condition at reduced draught.

The adjacent holds and decks are to be assumed empty.

The reduced draught is generally not to be considered larger than 0.8T.



Load Case 4

E.5.5 Tank test condition, side tanks full (LC-5F)

Side F.O. tanks are to be full in harbour condition at minimum ballast draught.

The adjacent holds and decks are to be assumed empty.

Load Case 5

E.5.6 Tank test condition, centre tank full (LC-6F)

One(1) centre F.O. tank is to be full in harbour condition at minimum ballast draught.

The adjacent holds and decks are to be assumed empty.

Load Case 6

E.6 Acceptance Criteria

Allowable stress and buckling control should be carried out according to the procedures described in section 5.6 and 5.7 respectively.