TÜRK LOYDU

Guidelines for the Structural Design Assessment of Ro-Ro Vessels

January 2023

This latest edition incorporates all rule changes. The latest revisions are shown with a vertical line. The section title is framed if the section is revised completely. Changes after the publication of the rule are written in red colour.

Unless otherwise specified, these Rules apply to ships for which the date of contract for construction as defined in TL- PR 29 is on or after 1st of January 2023. New rules or amendments entering into force after the date of contract for construction are to be applied if required by those rules. See Rule Change Notices on TL website for details.

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TÜRK LOYDU

Head Office	Postane Mah. Tersaneler Cad. No:26 Tuzla 34944 İSTANBUL / TÜRKİYE Tel : +90 216 581 37 00 Fax : +90 216 581 38 00 E-mail : info@turkloydu.org http://www.turkloydu.org
Regional Offices	
Ankara	Mustafa Kemal Mahallesi, Dumlupınar Bulvarı, Mahall Ankara B Blok Daire No:184 Çankaya - ANKARA / TÜRKİYE Tel : +90 312 219 56 34 Fax : +90 312 219 68 25 E-mail : ankara@turkloydu.org
İzmir	Atatürk Cad. No: 378 K.4 D.402 Kavalalılar Apt. 35220 Alsancak - İZMİR / TÜRKİYE Tel : +90 232 464 29 88 Fax : +90 232 464 87 51 E-mail : izmir@turkloydu.org
Adana	Çınarlı Mah. Atatürk Cad. Aziz Naci İş Merkezi No:5 K.1 D.2 Seyhan - ADANA / TÜRKİYE Tel : +90 322 363 30 12 Fax : +90 322 363 30 19 E-mail : adana@turkloydu.org

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SECTION 1

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A. Application

1. The **TL** Rules for Ship Classification specify a number of structural analysis requirements, including loads and acceptance criteria for the hull structures of RO/RO ships and car carriers.

2. This class guideline note specifies an acceptable method required for such structural assessments.

3 Strength analysis performed in compliance with the procedure specified in this class guideline note shall normally be recognized as the basis for class approval.

4. Any recognized calculation method or computer program for calculating structural response may be used, as long as the effects of bending, shear, and axial deformations are taken into account when applicable. If the wave loads are computed through a direct wave loading analysis, it is required to use a recognized software.

5. The objective of this class guideline note is:

- to provide a guidance for the design and evaluation of hull structures in RO/RO and car carriers in accordance with the TL Ship rules

- to provide a general specification on how to perform the required calculations and analyses

- to provide information on alternative methods for determining the racking response and fatigue damage of sensitive components

- to promote reliable designs through encouraging rational design and analysis methods.

B. Procedure

1. This class guideline note specifies how to utilize finite element analyses to carry out direct strength calculations for RO/RO ships. The calculation procedure is in accordance with requirements given in the **TL** Rules and is divided in two levels such as global and local, described as follows.

2. Global level: The global strength of the entire hull girder, including the contribution from the superstructure, is calculated and verified. The main results from the global analysis are the hull girder bending and shear stress response and pillar forces.

3. Local level: Local finite element models of areas are to have high stresses. Deflections obtained from the global models are utilized as load input. The aim is to determine that the stresses are within permissible limits.

4. When direct stress analyses are submitted for information, such analyses shall be accompanied by documentation satisfactory for verifying results obtained from the analyses as specified in the **TL** Ship Rules. As guidance, the documentation listed in this chapter should as a minimum be included.

C. Definition of Symbols and Abbreviations

1. The symbols used in this class guideline note are defined as below:

A.P. = after perpendicular

F.P. = forward perpendicular

x = longitudinal direction

y = transverse direction

z = vertical direction

LC = loading condition

g_0 = standard acceleration of gravity (9.81 m/s^2)

a_v = combined vertical acceleration as specified in TL Rules (Chapter 1, Hull, Section 5, A).

σ = normal stress

τ = shear stress

σ_e = equivalent stress (Von-Mises Stress, unless otherwise specified).

D. Documentation

1. Documentation of input data

All relevant input data shall be included in a report, such as:

- List of plans used including dates and versions
- Units used
- Detailed definition of modelling principles including possible deviations from construction drawings, assumptions, mesh definition, efficiency of curved flanges, eccentricity of beams, simplifications etc.
- Element types used in the model building
- Details of material properties used for all components
- Load cases considered
- Definition of applied loads

- Boundary conditions applied
- Proposed longitudinal still water bending moment and shear force envelope limit curves
- Values for vertical wave bending moment and shear force as given in the TL Rules (Chapter 1, Hull, Section 6)
- Plots documenting the plate thicknesses used such as color or numeric plots.

2. Documentation of results

The documentation of results shall include all relevant results such as:

- Boundary support reaction forces
- Directional and shear stresses for the load cases to demonstrate that the acceptance criteria are met
- Plots showing bending moment and shear force curves and corresponding tables with numerical values and calibration factors
- Plots of local and global deflections
- Numerical values for areas of high stress
- Plate buckling calculations
- Pillar forces and buckling calculations
- Plots of peak stresses
- For local analysis, plots of Von-Mises stresses also to be included for yielding
- Fatigue damage calculations
- Result discussion and quality check.

2. The stress presentation should be in accordance with element membrane stress or gauss membrane stresses, i.e. at the mid-thickness of the elements.

3. Information about the FEM software used shall be described. The calculations shall be performed by means of computer programs recognized by the **TL**.

E. Vessel Categorization

1. RO/RO

1.1 The term RO/RO refers to a ship specially arranged for roll-on and roll-off cargo handling.

1.2 Typical RO/RO cargo is cars, trucks, dumpers, containers, road trailers and MAFI trailers. The vessel is loaded either by use of the cargo's own engine power or by use of special loading and un-loading vehicles.

1.3 In general, RO/RO ships have deep transverse deck girders that can support the deck load without the need for pillars. The racking moment of each transverse frame is normally carried by the frame alone. This means that a simplified structural analysis approach can be utilized for the racking assessment of RO/RO ships with not more than two RO/RO decks above bulkhead deck.

1.4 The loading capacity of such ships is often indicated as lane metres.

2. RO/RO /Container

Several RO/RO ships are specially arranged also for transportation of containers. Such arrangement contains special fittings and lashing arrangement, and may also contain special cargo handling vehicles onboard the ship.

3. Car carriers

3.1 Car carriers are specially made for transportation of cars or other vehicles. In general such vessel has one or two side ramps in addition to the stern ramp (quarter ramp).

3.2 From a structural perspective, a car carrier is similar to a RO/RO ship but has more decks (i.e. 'Multiple decks RO/RO carrier'). A car carrier usually has different load carrying capacity for the different decks. The upper most decks are commonly designed for a low uniform deck load corresponding to the weight of private cars, down to 150 kg/m2 while some of the lower decks are built for a higher load and are intended for buses, trucks, trailers or other heavier vehicles.

3.3 Movable decks may in many cases be placed above the decks with higher specified load. Movable decks are either liftable, meaning free panels lifted by scissor lift on board the vessel, or hoistable, meaning that the panels are fitted with internal jigger winch and wires for lifting. The load capacity of the movable deck is similar as for the upper decks. The decks may be supported by pillars and longitudinal girders are then generally connecting the pillars.

3.4 Due attention shall be paid to the racking response of the hull structure:

- For smaller car carriers, the racking moment on each frame may be carried by the frame alone

- Smaller car carriers may also be designed assuming that the racking moment over a broader area of the cargo space should be carried by the same broad area

- For larger car carriers, the structure may be designed so that the racking moment for each frame section is not fully carried by the frame itself. Hence, the racking moment is transferred through the decks to stronger racking constraining structure. Bow, stern, engine casings, partial bulkheads, engine bulkhead, deep webs, and strengthened ventilation trunks are examples of racking constraining structures.

3.5 The load capacity of car carriers is normally given as number of cars, or free deck area (m^2).

4. Design concepts

For car carriers, there are two different structural concepts. These are the conventional rigid deck design and the hinged deck design. The hinged deck design is often referred to as the 'flexible' design. The term hinged deck design shall be used in this class guideline.

5. Conventional designs

A conventional Car Carrier design mean that the vertical side webs are aligned with the deck transverses (see Figure 1). This indicates that transverse forces on the decks will induce bending of the deck transverses. As a result, the frame section (vertical side and transverse deck girder) is rigid when exposed to transverse forces, compared to the hinged deck design. The frame section will carry a significant portion of the racking moment induced above the bulkhead deck (freeboard deck).

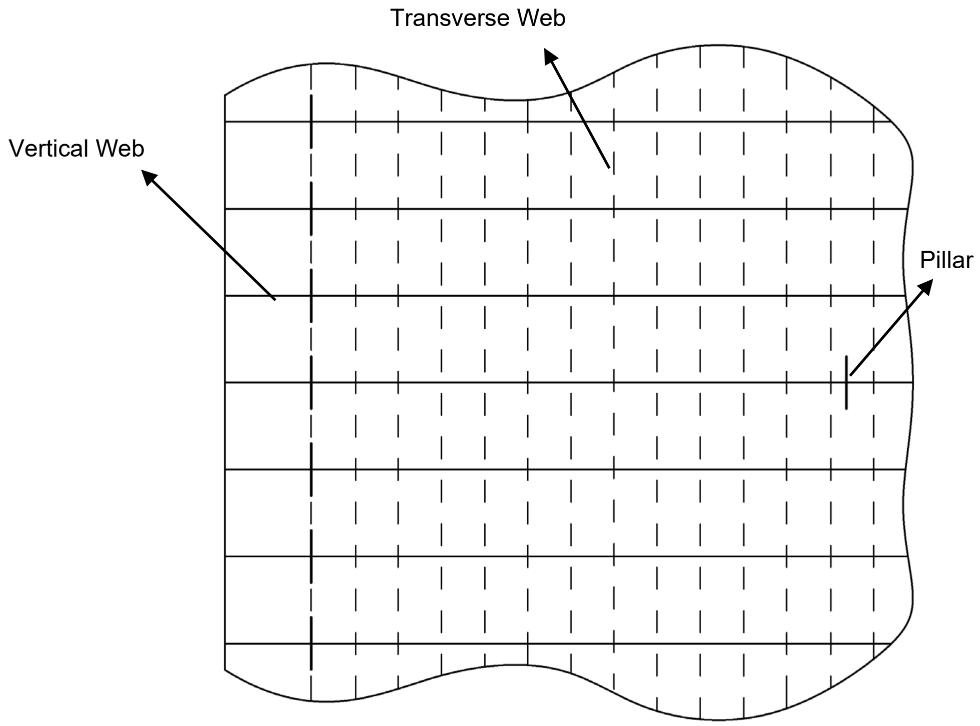

Figure 1 Typical deck plan for conventional (rigid deck design) car carrier

6. Hinged designs

6.1 A hinged deck car carrier design means that the vertical side frame is not in line with the deck transverse girder (see Figure 2). This means that no bending moment is induced in the transverse deck girder when the deck is subjected to transverse forces. The vertical side frame will then deform as a cantilever beam supported at the bulkhead deck and is only able to carry a reduced portion of the racking force on the transverse frame.

6.2 The bow region and the stern are then activated and contribute as racking constraining structure together with other main structure such as engine- and stair casings, deep racking webs and strengthened ventilation trunks.

6.3 The ability of ordinary side web frames to sustain transverse racking deformations of the upper hull is improved by an elastic hinge arrangement between the vertical web and deck girders. As a result, the side webs are usually thinner than in a standard design. However, in order to support the racking moment, the primary transverse racking restricting elements shall be strengthened.

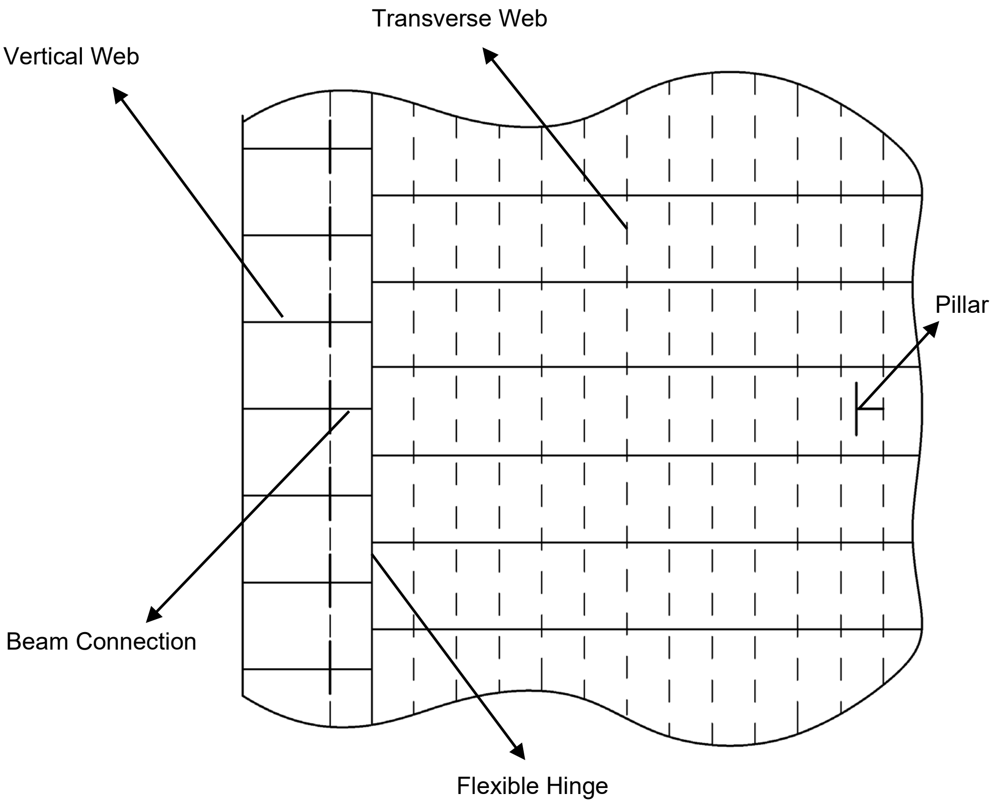

Figure 2 Typical deck plan for hinged deck design car carrier

6.4 Figure 2 shows how the longitudinal flexible hinge should have low torsional stiffness (flat bar is ideal) and the distance between the flexible hinge and the faceplate of the side girder should be as small as possible. Furthermore, the flexible hinge is supported, and the shear load shall be transferred to the side girders via short beams with sufficient web height to account for local bending.

6.5 The overall capacity of the racking constraining structures has, however, to be the same for a conventional (rigid deck) design as for a hinged deck design.

7. Operational considerations

7.1 Modern RO/RO ships travel between designated ports on a regular schedule. The majority of charters are for a long period of time. Depending on where the ship is trading, the weather and sea conditions may vary greatly. The behavior of the ship at sea shall be affected by changes in loading, which may change the long-term loads on the hull structure.

7.2 This class guideline note shall concentrate on typical loading conditions and load cases to ensure structural integrity during regular worldwide trade. Ship owners and/or operators having specific knowledge about loading conditions, trading routes, intended GM-values during operation should provide such information to the designer and/or yard as soon as possible when a new project is planned.

F. Sensitive Items and Areas

1. Wheel loaded decks

In addition to the effect of longitudinal hull girder forces, the deck structures are exposed to local loads from wheel print/axle loads and from container post loads where such arrangement is utilized. The rules have special requirements for wheel-loaded decks, with separate requirements depending on the direction of traffic relative to direction of deck plate stiffeners. Areas where the traffic direction is perpendicular to the direction of deck plate stiffeners are more prone to local plate deformation. For areas where cargo-handling vehicles are often operated, the effect of driving perpendicular to the stiffener direction should be specially accounted for.

2. Deflections in way of ramps

Deflections in way of ramps should be carefully accounted for. Satisfactory functionality and safe operation of ramps and movable decks depending on limited deflections of adjacent structure. Ramp openings may be closed by watertight ramps, ramp covers, doors or gas tight doors, and the designer should consider possible deflections of loaded deck girders above ramp opening, allowing for realistic deflections during normal operation.

3. Transverse racking

RO/RO ships have normally few racking constraining structural members that are effective related to support of transverse racking forces due to operational considerations. The fatigue influence of racking forces due to the rolling of the ship in combination with vertical dynamic acceleration should be assessed at an early phase of the design process.

4. Pillar structure

Pillars connecting two decks shall be designed to sustain the transverse relative deflection between the decks. Such connections may particularly be demanding when the deflections between the decks are high such as the hinged deck car carrier design.

5. Fixed ramps

Fixed ramps between two decks shall be designed to sustain the transverse relative deflection between the decks. This is particularly significant for decks above freeboard deck for the hinged deck car carrier design, in which fixed ramps must be divide into two parts or disconnected to one of the decks.

6. Ventilation ducts

To avoid stress concentration, ventilation ducts connecting several decks with large relative deflection between the decks shall be built with sufficient flexibility.

7. Garage on upper deck

To avoid stress concentration the connection between the garage and the upper deck shall be designed with sufficient flexibility. The racking strength of the garage itself requires specific care.

8. Transverse bulkheads

For vessels with a reduced number of effective transverse bulkheads or transverse bulkheads with reduced vertical shear capacity due to openings or ramp penetrations, the effective vertical shear capacity shall be specially accounted for.

9. Bottom girders

Bottom longitudinal girders in the cargo area may be subjected to large shear forces in way of their end supports. This commonly applies in way of the engine room bulkhead, cargo space front bulkhead and connection to partial longitudinal bulkhead in way of internal ramps.

10. Floors

Special attention should be made to openings and cut-outs in the tank top in cases where a rigid lower side structure provides end support for the bottom without allowing rotation, since this will decrease the top plate flange. In order to strengthen the double bottom, local buckling in combination with stiffening direction shall be accounted for.

11. Internal ramps, stern- (quarter) and side ramps

11.1 Internal ramps, stern and side ramps are all exposed to loads during cargo operations and from lashed vehicles. Deck plating and stiffeners exposed to wheel loads shall be dimensioned accordingly. Ramps forming part of the external side shell shall also be dimensioned for applicable sea pressure. Stern ramps extending above upper deck are in addition exposed to loads from seas on upper deck.

11.2 Ramps should also be carefully evaluated related to supporting and securing arrangement considering the actual inertia loads that apply. The flexibility of the surrounding structure to the ramp should be assessed.

SECTION 2

HULL GIRDER STRENGTH

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1. Ship Side Openings

A. Hull Girder Bending Strength

1. Wave Bending Moment

1.1 RO/RO ships and Car Carriers have a modest speed and large flare. Therefore, the wave sagging moment in accordance with the rules should be adjusted for the speed effect and the flare effect for buckling check of upper decks and shipside.

1.2 A similar correction should be performed to the hogging moment and the corrected hogging moment shall only utilized for buckling capacity checks. The distance from summer load waterline to the deck line used to determine the flare factor, should be taken to the lowermost deck in which water can be entrapped and produce raise to an increased hogging moment. The distance should be considered to the mooring deck for designs with open mooring deck forward.

B. Hull Girder Shear Strength

1. Ship Side Openings

Shear stress should be taken into account when large openings in the shipside are present. One way to analyze the shear stress is to determine the part of the total shear force which shall distribute above and below the side opening in accordance with the relative stiffness of the ship side above and below the opening.

SECTION 3

PRIMARY SUPPORTING STRUCTURE ASSESSMENT

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5. LC4 and LC5 - Unsymmetrical static load patterns
6. LC6 Heavy cargo unit on single girder
7. LC7 Flooded condition
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A. FE Partial Ship Model

1. For multi deck RO/RO ships and Car carriers, the primary supporting members shall usually be evaluated from a FE partial ship model. This section defines special modelling issues and load application.

2. The analysis model should extend over minimum three (3) pillar spacings. The model should cover the full breadth of the ship in order to consider for unsymmetrical load cases (LC4 and LC5).

3. FE Model

A general definition of FE partial ship model including structural idealization, mesh, element size and boundary conditions are given. A typical mesh arrangement on transverse web frame is shown in Figure 1.

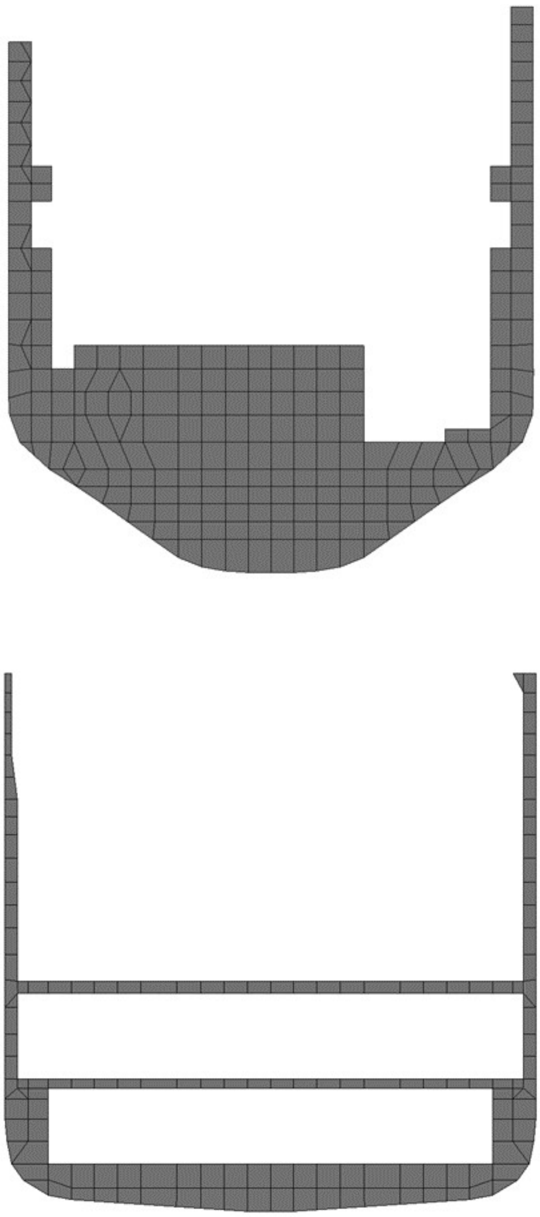

Figure 1 Typical mesh arrangement on transverse web of a car carrier

4. Structural idealization

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

B. General Load Application

1. The main symbols and abbreviations used throughout in these guidelines are given below:

2. LC1 Normal ballast draught with no Cargo

2.1 This loading condition normally contains:

- Maximum still water hogging moment envelope limit curve; and
- Wave hogging moment distribution.

2.2 The load case may be crucial for the double bottom. Double bottom bunker tanks shall be accounted for empty. Ballast in double bottom tanks may be included as counteracting forces to the external pressure. The counteracting force related to the gravity effect of the mass of water in the ballast tanks.

2.3 This loading condition shall normally be crucial for the scantling of the following structural components:

- Upper decks with corresponding to tensile stress level
- Longitudinal structure related to shear stress
- Longitudinal bottom structure related to compressive buckling stress
- Pillars due to load-contribution from global bending
- Stress concentration areas such as openings, cut-outs in upper sides, bulkheads, and decks.

3. LC2 Maximum cargo load on lower decks

3.1 This loading condition normally contains:

- maximum still water sagging moment or minimum still water hogging moment envelope limit curve
- wave sagging moment distribution

3.2 The load case may be crucial for the lower decks and pillars. It is noted that the higher decks are also loaded, although not to its maximum load capacity, to establish vertical balance at scantling draught.

3.3 This loading condition shall normally be crucial for the scantling of the following structural components:

- upper decks and longitudinal bulkheads corresponding to buckling
- stress concentration areas such as openings, cut-outs in upper sides, bulkheads, and decks.

4. LC3 Maximum cargo load on upper decks

The load case may be critical for the double bottom, higher decks, pillars and longitudinal girders in the double bottom area. All cargo tanks, except the tank top, shall normally be accounted for loaded to maximum values.

5. LC4 and LC5 - Unsymmetrical static load patterns

5.1 This load case may be dimensioning for the longitudinal and transverse deck girders.

5.2 Unless specific limitations to the loading are defined as a design basis, the highlighted zone in Figure 2 and Figure 3 shall be loaded with maximum uniform distributed load (UDL) and with no cargo load on the remaining deck part for LC4 and LC5, transversely- and longitudinally unsymmetrical load patterns.

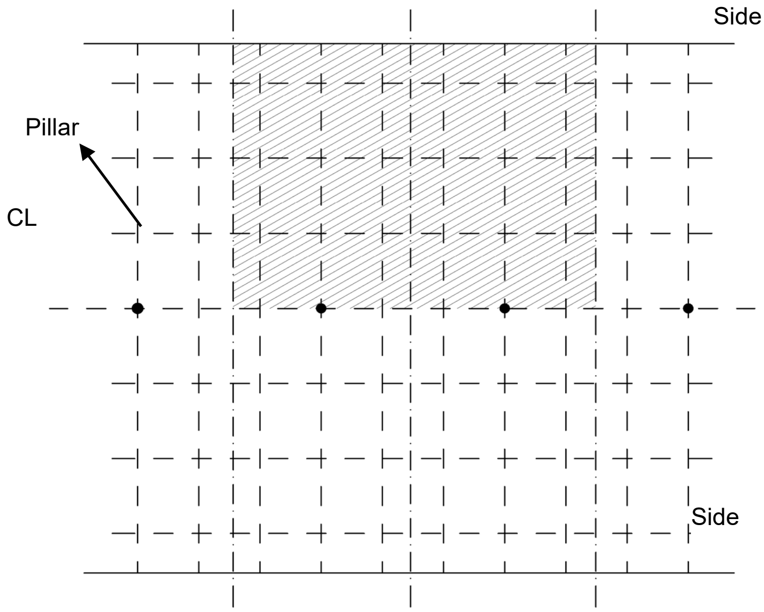

Figure 2 Load case LC4

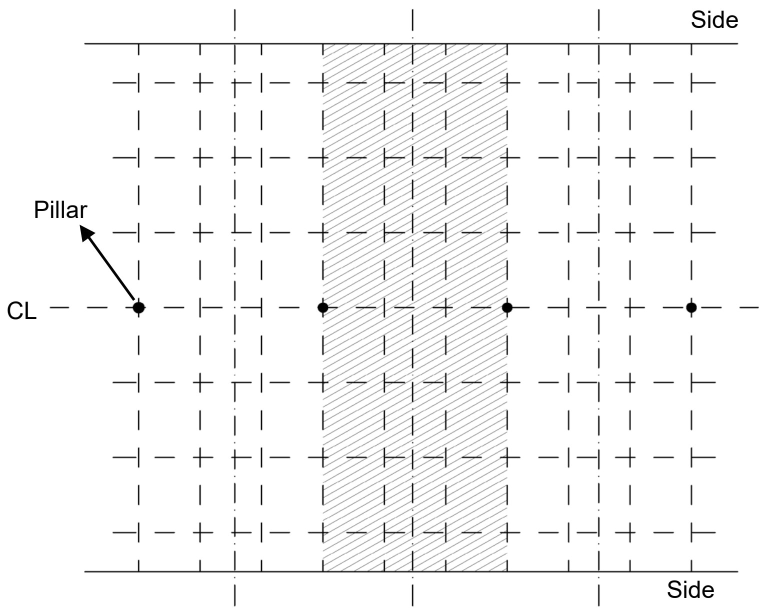

Figure 3 Load case LC5

5.3 For two-pillar system, the load between the pillars and the load outside the pillars shall be evaluated separately.

6. LC6 Heavy cargo unit on single girder

6.1 The load case may be critical for transverse girders on heavy cargo decks, in particular related to shear stress in girder webs towards pillar connections.

6.2 Maximum number of bogie loads, side by side, to be applied to one single girder according to stowage plan. The following load patterns should be evaluated:

- Maximum bogie loads on the transverse girder in way of the pillars from side to side

- Maximum bogie loads on the transverse girder in way of the pillars, only between the pillars

- Maximum bogie loads on the transverse girder located in the middle between the pillars, from side to side.

7. LC7 Flooded condition

7.1 The load case is critical for the watertight decks.

7.2 The watertight decks shall be loaded in accordance with applicable final equilibrium waterline for the deck in question. No cargo shall be applied on the watertight decks.

8. LC8 Bow impact condition

8.1 The fore ship is frequently exposed to bow impact.

8.2 For the evaluation related to bow impact for conventional hull shapes, Chapter 1, Hull are to be referred.. However, for unconventional design with extreme flare angle or when the decks in the fore ship have large openings and steps, a direct bow impact analysis may be essential to confirm the whole strength of the bow structure.

8.3 The largest vertical bending moments in the bow region are anticipated when the largest bow impact loads are present. This takes place for the highest vertical relative velocity when the bow enters the water. Therefore, the design wave shall be selected to simulate the most probable largest vertical velocities at FP during 20 years operation. To get this design wave the relative motion at FP should be employed.

8.4 When this loading condition is relevant, it shall normally be critical for the scantling of the following structural components:

- Longitudinal bulkheads and decks in the fore ship related to compressive buckling stress.

C. Wave Load Analysis

1. If a direct wave load analysis is performed, the analysis will be subjected to special consideration. Wave loads shall be calculated with a recognized software tool which can demonstrate results to the satisfaction of the **TL**.

SECTION 4

GLOBAL RACKING ASSESSMENT

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A. Modelling

1. The whole aim for the global model is to represent the global stiffness satisfactorily related to the objective for the analysis. The effectiveness of the superstructure is depending on its length, the flexibility of its supports, the integration with the hull girder at its ends, and the extent and number of openings in side bulkheads and intermediate decks.

2. All effective longitudinal material shall be included. All transverse primary structures such as watertight and fire bulkheads, and transverse webs shall be included in the FE model. Local details are not included in the global FE model.

3. The goals of the global modelling analysis are to:

- Determine the longitudinal hull girder stresses

- Determine stresses in transverse structures due to racking

- Obtain forces in pillars

- Apply boundary conditions for the local analysis

4. The following sub-sections provide additional input regarding the global FE model.

5. Scantlings

The scantlings for longitudinal members may be modelled with gross scantlings. The transverse members shall be modelled with reduced scantlings such as corrosion addition in accordance with the TL Rules (Chapter 1, Hull) shall be deducted from the actual (gross) scantlings.

6. Structure representation

All racking constraining structural members such as decks, external shell, bulkheads, racking constraining girder structures, deep webs, engine casing, bow, stern bulkheads and partial bulkheads should be included in the FE model. The deck panels including the deck stiffeners may be represented by plate elements and the girder structures by eccentric beam elements. Gross scantlings may be applied.

B. Mesh Size and Element Type

1. The size and type of plate elements applied shall give a satisfactory representation of the deflection and stress distribution within the ship hull structure. Different types of elements may be utilized in the global FE model.

2. 8 and 6 node elements should be used. The use of 4 and 3 node elements shall require half mesh size. Due attention should be paid to the element shape; especially in case 4 and 3 node elements are used. Sharp corners, skewed elements and excessive use of triangle elements (6 and 3 nodes) may lead to errors in the resulting deflection patterns in the FE model.

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

4. The 8 and 6 node membrane elements with three layers representing plate, stiffener web and flange, provide a good representation of the stiffness longitudinally, transversely and in shear.

5. A typical global coarse mesh models of a RO/RO ship is shown in Figure 1.

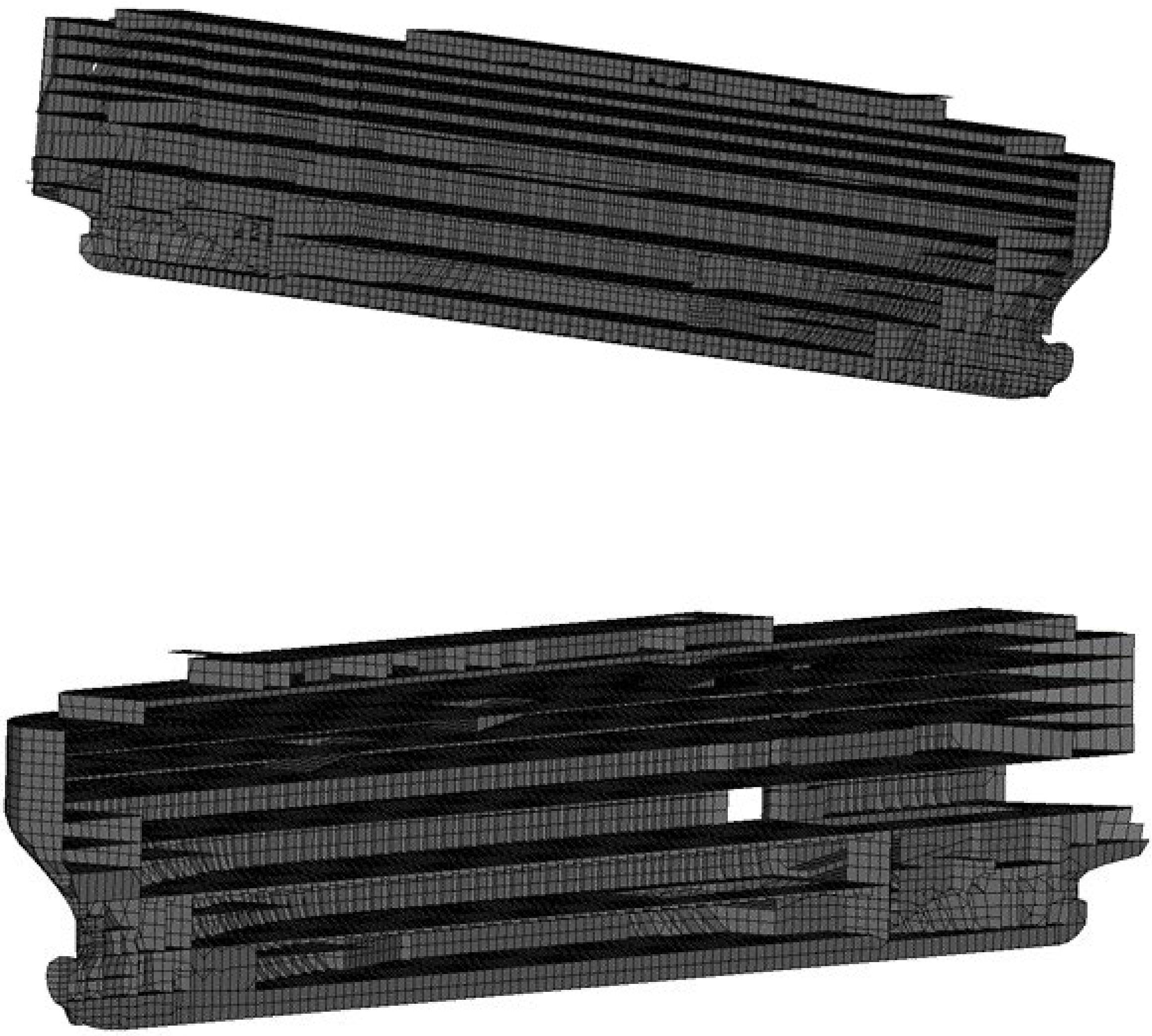

Figure 1 Global coarse mesh finite element model of a RO/RO ship (only half the model shown)

6. Pillars

Pillars should be represented by beam elements having axial and bending stiffness. Pillars may be described as 3 node beam elements, or 2 node beam elements when 4 and 3 node plate elements are utilized.

7. Longitudinals and stiffeners

Longitudinal stiffeners are lumped to nearest mesh-line described as 3 and 2 node beam elements.

8. Mesh density

8.1 The element type and mesh fineness should be chosen to demonstrate the overall stiffness of the hull girder. Stresses decomposed in the model's main directions shall be applied in direct control of buckling and maximum permissible stress.

8.2 In general, the plate element mesh follows the primary structural arrangement. Typical acceptable mesh divisions could be as below:

- for longitudinal: 3-4 m, at least one element between every web frame

- for transverse: 3-3.5 m

- for vertical: 1-2 elements between decks

- for bilge: 2 elements over the curved area

- for double bottom girders: 1 element over the height.

9. Effective flange

When using element mesh size equal to the web distance then the effective flange shall not be properly represented, and results shall be used with attention.

10. Openings

All window openings, door openings, deck openings and shell openings of significant size shall be represented. The openings shall be modelled such that the deformation pattern under hull shear and bending loads is sufficiently represented. Any idealization adopted shall be validated by means of check models and comparison with the performance of appropriate fine mesh models. A typical fine mesh opening FE model is shown in Figure 2.

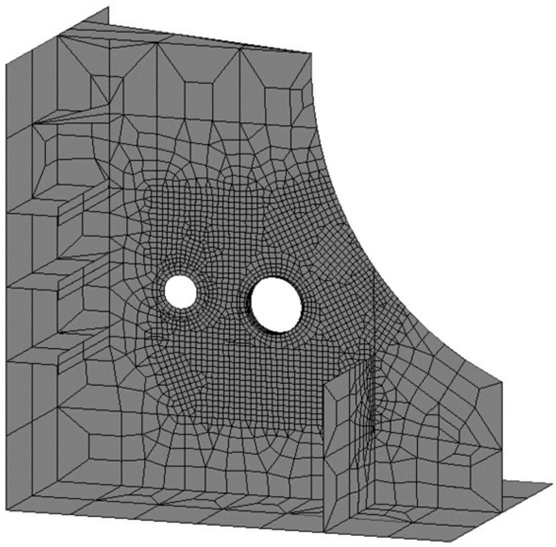

Figure 2 A fine mesh opening FE model shown

11. Boundary conditions

11.1 The boundary conditions should be defined only to avoid rigid body motions. The reaction forces in the boundary nodes should be minimized.

11.2 A typical boundary conditions applied for global FE model is shown in Figure 3.

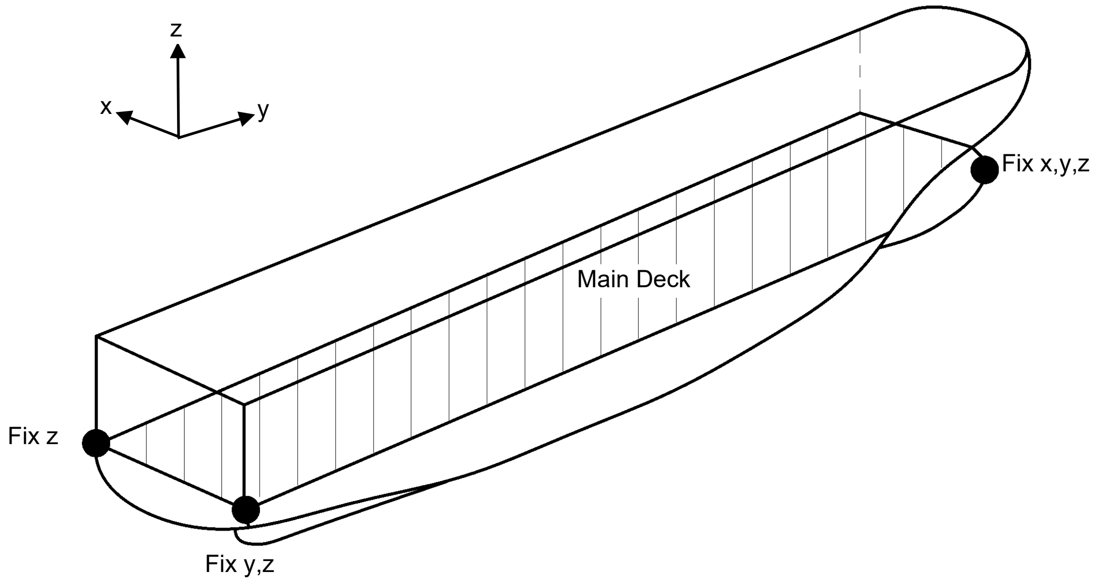

Figure 3 Boundary conditions applied for global FE model

12. Balancing of global FEM model

It is critical that the loads on the global FEM model are balanced and that reaction forces are kept to a minimum. The reaction forces will show how evenly the forces are distributed. None of the reaction forces should be more than 2% of the structure's overall weight.

13. Reporting of structural analyses

13.1 The global transverse strength analysis of the vessel should be submitted to TL as information.

13.2 The following should as a minimum be included in the analysis report:

- Drawings and loading manuals as basic input
- Range of the model including eccentricity of beams, efficiency of curved flanges, assumptions, representations and simplifications
- Units considered
- Computer tool program name and version

- Type of elements used in the model
- Property applied to model such as thickness
- Boundary conditions applied
- Load description including load directions
- Load balance
- Sum of loads and reactions
- Result plots
- Displacement and deformation plots
- Numerical values for areas of high stress
- Plots of peak stresses
- Results demonstrated for equivalent stress (VonMises), transverse stresses, shear stresses, in plane stresses, and axial stresses. **TL** may request the display of stress values according to different integration point results. (Averaged, unaveraged etc.)
- Result discussions and quality check.

14. Structural elements to be reviewed

14.1 Structural elements shall be checked against racking are:

- for yielding check: transverse elements subject to transverse loads (side shell frames, central casing frames and transverse bulkheads) and connection between beams and vertical web frames.
- for buckling check: decks, side shell and central casing plating.

14.2 Other components might be critical depending on the design.

C. Loads and Loads Application

1. General

The global analysis model shall accurately represent the real mass distribution of the hull structure as well as other mass components. The FEM analysis results should be controlled by integrating the stresses at numerous cross sections to ensure that the imposed loading produces the correct global bending moment and shear force.

2. Loading condition

2.1 The loading conditions resulting in the highest racking moment about bulkhead deck shall be selected for the racking strength analysis.

2.2 For fatigue damage assessment, the most frequent loading condition should be the basis.

2.3 To simplify the design process, the same loading conditions as for strength may be considered for the fatigue damage assessment, even if it could be a conservative way, depending on the design and loading manual.

3. Dynamic Deck Loads

The dynamic deck loads may be applied as surface pressure in the global FE model.

4. Sea Pressure

In accordance with **TL** Rules (e.g. Chapter 1, Section 5), the sea pressure shall be applied as surface pressure to the bottom and side structure.

5. Machinery and Outfitting

All major components such as main machinery, main generators, rudder, etc. should be modelled as point masses attached to the surrounding structure at their correct positions. The weight of a component may be split into several mass points if the component is too large (e.g. the main machinery).

SECTION 5

DOCKING ASSESSMENT

Page

A. Modelling and Load Application **5-2**

B. Aft Structure **5-2**

A. Modelling and Load Application

1. Large RO/RO ships have a large docking weight, and special care should be taken to assess the bottom structure in way of the docking blocks, where the docking analysis should be considered as a separate load case in the FEM analyses.

2. When required, a separate docking load case should be applied to the global FE model based on the lightship weight and the docking plan.

3. Spring elements should be added as boundary conditions to model the docking blocks.

4. These guidelines may be applied for the separate docking loading case shall usually be decisive for the dimensioning of the following structural areas:

- shear buckling of floors and girders in the double bottom.

- capacity of double bottom structure and support.

B. Aft Structure

1. The docking assessment shall provide a good overview of the vertical deflections for ships with extended flat bottom design in the aft structure. It may be essential to add supporting pillars/docking blocks under the flat bottom during docking if the analysis demonstrates considerable deflections.

SECTION 6

LOCAL FINITE ELEMENT – FE MODEL

Page

A. **General** 6-2
B. **Sub Modelling** 6-3
C. **Fine Mesh Analysis** 6-4

A. General

1. Typical critical structures are the main transverse racking constraining members of the hull such as bow, stern, partial transverse bulkhead, the machinery bulkhead, engine casing front wall, shell, and deck structures in way of racking bulkheads and deep webs and typical pillar and web frame connections to lower decks.

2. Local models of components and structural areas with high stresses shall be modelled. Whole aim of the local analyses is to determine that the stresses are within permissible limits.

Figure 1 shows a typical local models.

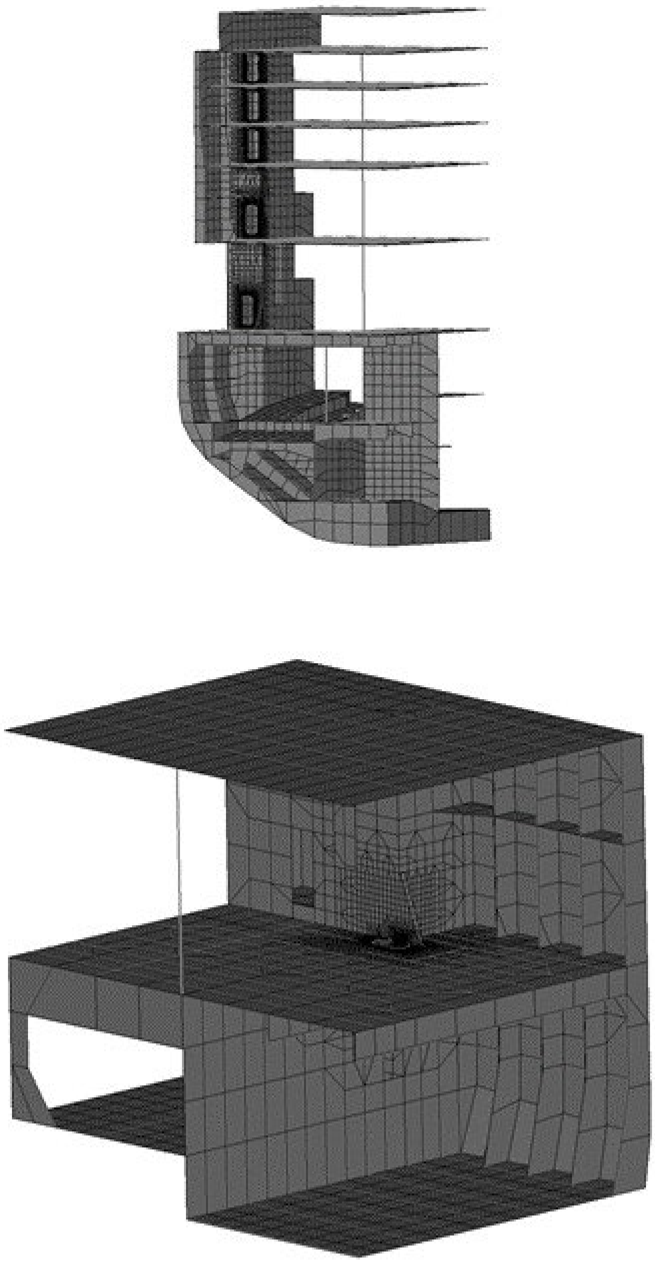

Figure 1 Typical local RO/RO ship models.

B. Sub Modelling

1. Using a sub-modeling technique, the local FE model can be built independently of the global FE model. The local model can also be integrated into the global FE model. The loads on the local FE model should be imposed as forced deformation or nodal forces in the boundary nodes if a sub-modeling technique is used. It is necessary to document the consistency of the global and local models in terms of boundary forces and nodal deformations.

2. Separate detailed fine mesh finite element (FE) models including the structural components that are selected that shall be built and loaded with imposed displacements or forces derived from the full ship global analysis.

3. Extension of local model

3.1 The size of the fine mesh model is to be such that the application of boundary displacements taken from the global FEM analysis shall not invalidate the response at the relevant points of the local fine mesh model.

3.2 The local model shall contain stiffeners, brackets, all openings, cut-outs, and other local details that affect the stresses in the relevant areas. The level of detail should be sufficient that stress concentrations can be identified.

4. Mesh definitions

Mesh size shall have a direct impact on the results calculated from the local FE-analysis. It is hence outmost importance that the element size is chosen to produce realistic results. Previous experience with FEM analysis and calibration experiments where element analysis results have been compared with full-scale measurements shows that a mesh size comparable to that of the modelled plate thickness provides accurate results.

5. For corners in openings where only the peak stress is of interest, the mesh fineness is not to be larger than 0.2R, where R is the radius of curvature of the corner. This is relevant for in plane stresses only. The primary structure in the local model shall be represented by plate elements having both membrane and bending capability. Secondary stiffeners away from stress concentration areas may be represented by beam elements.

6. Localized hot spots

For very localized hot spots, the model may have a variation of mesh density with a fine mesh area at hotspot localization. Outside, the mesh may be greater, provided that a smooth transition is applied between outside and inside the fine mesh area.

Figure 2 Typical a localized hot spot model.

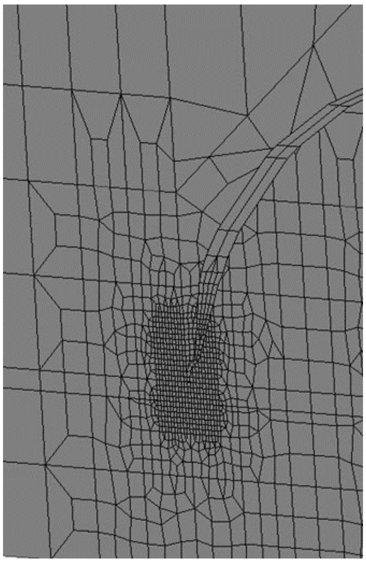

Figure 2. Typical a localized hot spot model

C. Fine Mesh Analysis

1. Fine mesh size should not be greater than 50 x 50 mm and in addition, the mesh size should allow a correct description of the structure and a good representation of stress flow.

2. A fine mesh analysis should be carried out for the following structural items:

- Openings in webs of longitudinal girders and in webs of transverse deck beams and girders
- Bulkhead door openings
- Engine room casing
- Large openings in upper decks
- Large openings in longitudinal bulkheads
- Ends of the side decks strips of the uppermost continuous deck
- Corners of shell doors openings
- Atriums
- Corners of window openings
- Transverse bulkhead openings.

SECTION 7

ACCEPTANCE CRITERIA

Page

A. General **7-2**

2. Minimum thickness

B. Buckling **7-2**

C. Longitudinal Strength **7-2**

1. Nominal stresses

D. Peak Stress **7-3**

E. Pillars **7-3**

1. Compression
2. Tension

F. Racking **7-3**

1. Nominal stresses

G. Docking **7-4**

A. General

1. This section presents acceptance criteria used for the different types of stress and strength analyses.

2. Minimum thickness

The final thickness of the considered structure shall not be less than the minimum thickness given in the **TL** Rules (Chapter 1, Hull).

B. Buckling

1. The plate buckling requirements shall be applied in accordance with **TL** Rules (Chapter 1, Section 3). The critical buckling stress of plate panels shall be derived considering all applicable compressive and shear stress components.

C. Longitudinal Strength

1. Nominal stresses

Permissible nominal stress for maximum hogging (LC1) and maximum sagging (LC2) condition is as below:

σ_l = 175/k (MPa) within 0.4 L amidship
= 125/k (MPa) within 0.1 L from AP or FP

Between specified positions sl shall be varied linearly.
τ = 110/k (MPa)
σ_e = 235/k (MPa)

Note: The material factor k included in expressions giving permissible stresses, depending on strength group as below:

- for TL-NS: k =1.00
- for TL-32: k =0.78
- for TL-36: k =0.72
- for TL-40: k =0,68 (See also Chapter 1, Section 3, Table 3.1)

2. Permissible Deflections

The maximum permissible elastic deflection of a loaded girder, with the length "ℓ" under consideration shall be:

$$f_{perm} = \frac{\ell}{500} \quad \text{for steel structures}$$

$$= \frac{\ell}{300} \quad \text{for aluminium alloys}$$

D. Peak Stress

1. The acceptance criteria for peak stresses from fine mesh models shall normally be; σ_e = 400/k (MPa)

The acceptance of this is based on fine meshed FE-models, small areas above yield and that the neighbouring structures have capacity to take the load. Acceptance of stress results as “peak stresses” and use of above acceptance criterion are to be agreed by **TL** and **TL** has right to impose stricter requirements.

2. Applicable for base material with no welding close to the edge, that the plastic mechanism are not developed in the associated structural parts and that the buckling capacity is adequate to sustain the forces in compression.

E. Pillars

1. Compression

The compressive forces shall be checked against the critical buckling load calculated from the **TL** Rules, Part A, Chapter 1, Hull Section 8, D, 3.1 (see also below). When the axial load component from global bending is accounted for in combination with forces as specified in **TL** Rules, Part A Chapter 1 Hull Section 8, D, 3.1, η_{buck} may be taken 0.75.

$\eta < \eta_{buck}$

η, Buckling Utility Factor = σ / σ_{cr};

σ , Buckling Stress (Calculated)

σ_{cr}, Minimum Critical Buckling Stress (see **TL** Rules, Part A, Chapter 1, Hull Section 8, D, 3.1)

η_{buck} 0.65 or 0.75 (see above)

2. Tension

It is also a part of the analysis to identify pillars exposed to tensional forces. The permissible axial stress in tension is:

$\sigma_{tension}$= 160/k

The local support of tension-exposed pillars shall be carefully assessed. Full penetration welds shall normally arranged in way of the end connections.

F. Racking

1. Nominal stresses

For the loading condition transverse racking (LC3) the following permissible nominal stresses apply:

σ = 160/k (MPa)

τ = 90/k (MPa)

σ_e = 235/k (MPa)

2. Permissible Deflections

The maximum permissible elastic deflection of a loaded girder, with the length "ℓ" under consideration shall be:

$$f_{perm} = \frac{\ell}{500} \quad \text{for steel structures}$$

$$= \frac{\ell}{300} \quad \text{for aluminium alloys}$$

G. Docking

1. The design pressure by the footprint of the docking blocks should normally not exceed 2 N/mm^2. For girders in the double bottom, the following allowable nominal stresses apply provided the buckling strength is adequate:

σ = 220/k (MPa)
τ = 120/k (MPa)
σ_e = 235/k (MPa)

2. The double bottom structure shall be specially checked for buckling capacity in accordance with the requirements given in the **TL** Rules (Chapter 1, Hull, Section 3).

A. General

1. Structure designed with complex details and abrupt connections are prone to cracking when exposed to repeated dynamic loadings. The predicted fatigue life may be increased good design of details and weld connections in combination with good workmanship and final grinding of welds (at fabrication stage).

2. The peak stress levels obtained from the local models form the basis for calculating the fatigue life of the structure. Fatigue damage assessment normally provides a lower acceptable stress level than the peak stress criteria.

3. The fatigue analysis shall be carried out in accordance with the net thickness.

4. The fatigue life shall not be less than 20 years for each considered detail.

B. Scope and Critical Areas

1. For Car Carriers where a limited number of transverse bulkheads are supporting the racking (transverse) moment, fatigue damage assessment may be required for the following structural items;

- Transverse bulkheads and deep web structure with small radii openings including bow and stern.
- Connection of engine room, stairway casing bulkheads to bulkhead deck.
- Connections between transverse deck girders and vertical girders (cruciform joints).
- Connection of other racking constraining structure such as racking boxes in cargo area to lower decks.
- Connection between transverse deck girders and racking constraining structure such as casings and racking boxes.
- Transverse girder connection to webframe in way of weather deck.
- Connections of vertical girders to bulkhead deck.
- Pillar connection to topdeck girder.
- Pillar connection to transverse deck girders and inner bottom.

2. Additional fatigue scope may be required based on simplified method:

- Longitudinals below main deck.
- Transverse and/ or longitudinal block seam in upper deck if seen critical.
- Most critical shear plate connection to web frame in shipside for hinge car carrier designs.

3. Self-supporting frames

For Ro/Ro and smaller Car Carrier designs where each frame is self-supporting and when subjected to racking loadings, the following items may be investigated for fatigue damage assessment:

- Connections between transverse deck girder and vertical web frames in ship side

- Connections of vertical girders to freeboard deck (or where vertical girder are to be considered fixed to rigid body).

APPENDIX

TECHNICAL VERIFICATION FOR FINITE ELEMENT MODELS AND RESULTS

Page

A. Application .... **A-** 1

A. Application

1. The Analyst and the Verifier of the finite element report undertake separate evaluations. The highest level of overall check deals with five important areas of finite element analysis such as;

1.1 Preliminary checks

Checking of the analysis documentation, job specifications, FEA software and analyst qualifications.

- Documentation
- Job specification acceptability
- FEA software utilized
- Analyst qualifications

1.2 Engineering model checks

Checking to ensure that the assumptions utilized to develop the engineering model of the problem are appropriate.

- Analysis type and assumptions
- Geometry
- Material properties
- Stiffness and mass properties acceptability
- Dynamic Degrees of Freedom (DOF)
- Loads and boundary conditions applied

1.3 Finite Element model checks

Checking to ensure that the finite element model is a sufficient interpretation of the engineering model.

- Element types
- Mesh design acceptability
- Substructure and sub-models
- FE loads and boundary conditions applied

1.4 Finite Element results checks

Checking to ensure that the finite element results are computed, processed and presented in manner consistent with the analysis requirement.

- General solution checks

- Displacement results acceptability

- Stress results

- Other results

1.5 Conclusion checks

Checking to ensure that sufficient consideration of the loads, strength, acceptance criteria, FE model, and results accuracy are included in the conclusion part.

- FE results and acceptance criteria

- Loads assessment

- Strength and resistance assessment acceptability

- Accuracy assessment

- Overall assessment

1.6 This Quality Management System should be established and presented in the final FEA report. A well-documented and well-understood job description is clearly required.