Section 2 Global Strength Analysis

1 General

1.1 Application

1.1.1 The global strength analysis is to be carried out in order to check the hull girder stress in relation to maximum permissible stress and buckling stress (see [2.2] and [2.3]).

1.1.2 Material

The global strength analysis of monohull and multihull is to be carried out taking into account:

- for steel structure: the present Section
- for aluminium structure: the present Section and NR561 Aluminium Ships
- for composite structure: the present Section and NR546 Composite Ships.

1.1.3 Application

a) Monohull ships and float of multihull:

For monohull ships and for floats of multihull, the global hull girder longitudinal strength is to be examined in the following cases:

- ships with length greater than 40 m, and 30 m for ship built in composite material, or
- ships having large openings in decks or significant geometrical structure discontinuity at bottom or deck, or
- ships with transverse framing systems, or
- ships with deck structure built with large spacing of secondary stiffeners, or
- cargo ship as defined in Ch 1, Sec 1, [2.1.3], or
- where deemed appropriate by the Society.

For ships not covered by the above cases, the hull girder strength is considered satisfied when local scantlings are in accordance with requirements defined in Sec 3 and in Sec 4.

b) Platform structure of multihull:

As a rule, the global transverse strength of platform of multihull is to be examined for all types of multihull.

1.2 Global strength calculation

1.2.1 General

The global strength of monohull and multihull are to be calculated according to:

- [3] and [4] for monohull and catamaran respectively, or
- finite element calculation according to [5], or
- an equivalent alternative calculation approach submitted by the designer

1.2.2 Where a member contributing to the longitudinal and/or transversal strength is made in material other than steel with a Young's modulus E equal to 2,06 10^5 N/mm², the steel equivalent thickness area that may be included for the calculation of the inertia of the considered section is obtained, in mm², from the following formula:

$$t_{SE} = \frac{E}{2{,}06.10^5} t_M$$

where:

t_M : Thickness, in mm², of the member under consideration

E : Young modulus, in N/mm², of the considered member.

1.2.3 Finite element calculation

The global strength analysis may also be examined with a Finite Elements Analysis submitted by the Designer. In this case, and where large openings are provided in side shell and/or in primary transverse cross structure of platform of multihull for windows, doors..., a special attention is to be paid to ensure a realistic modelling of the bending and shear strength of the jambs between openings.

2 Global strength check

2.1 General

2.1.1 The global analysis check is to be successively carried out taking into account the scantling criteria based on maximum stress check (see [2.2]) and on buckling check (see [2.3]).

The global analysis check is to be carried out in the following areas of the hull:

- in head sea condition (for monohull and multihull):

  Along the ship from 0,3L to 0,7L from the aft end

- in quartering sea (for multihull only):

  Along the float from aft to fore end, and in way of each primary transverse cross structure of the platform.

2.2 Maximum stress check

2.2.1 Steel and aluminium structure

It is to be checked that the actual normal stresses σ_A, in N/mm^2, and the actual shear stresses τ_A, in N/mm^2, calculated according to [3] and, for multihull, to [4] are in compliance with the following criteria:

$$|\sigma_A| \leq \sigma_{glam}$$

$$|\tau_A| \leq \tau_{glam}$$

where:

σ_{glam} : Global bending permissible stress, in N/mm^2, as defined in Ch 2, Sec 3

τ_{glam} : Global shear permissible stress, in N/mm^2, as defined in Ch 2, Sec 3.

2.2.2 Composite structure

It is to be checked that the actual normal stresses and shear stresses, calculated according to [3] and, for multihull, to [4] are in compliance with the criteria defined in Ch 2, Sec 3, [3.1].

2.3 Buckling check

2.3.1 Steel and aluminium structure

It is to be checked that the actual normal stresses σ_A and shear stresses τ_A calculated according to Article [3] and, for multihull, to Article [4] are in compliance with the criteria defined in App 1.

2.3.2 Composite structure

a) Stress check:

It is to be checked that the actual normal stresses σ_A and shear stresses τ_A calculated according to Article [3] and, for multihull, to Article [4] are in compliance with the following criteria:

$$|\sigma_A| \leq \frac{\sigma_c}{SF_B}$$

$$|\tau_A| \leq \frac{\tau_c}{SF_B}$$

where:

σ_c, τ_c, : Critical buckling stress, in N/mm^2, in compression and in shear in the whole panel as defined in NR546 Composite Ships

SF_B : Permissible safety factor defined in Ch 2, Sec 3, [3.2.3].

b) Midship section of inertia:

As a rule, the midship section moment of inertia is to be in accordance with NR546 Composite Ships [4.4],

2.3.3 HDPE structure

According to NR546 Composite Ships, Sec 10 [1.2.2] for ships able to sail in planning mode, it is to be checked that the actual normal stresses and shear stresses induced by loading cases defined in Ch 3, Sec 2, [6.1] and calculated according to Article [3] are in compliance with the criteria defined in App 1.

3 Calculation of global strength for monohull ship

3.1 General

3.1.1 The calculation of the hull girder strength characteristics is to be carried out taking into account all the longitudinal continuous structural elements of the hull.

A superstructure extending over at least 0,4 L may be considered as contributing to the longitudinal strength.

The transverse sectional areas of openings such as deck hatches, side shell ports, side shell and superstructure doors and windows, in the members contributing to the longitudinal hull girder strength, are to be deducted from the considered transverse section.

Lightening holes, draining holes and single scallops in longitudinal stiffeners need not be deducted if their height is less than 0,25 h_W without being greater than 75 mm, where h_W is the web height, in mm, of the considered longitudinal.

Bilge keels may not be included in the hull girder transverse sections, as they are considered not contributing to the hull girder sectional area.

3.2 Strength characteristics

3.2.1 Section modulus

The section modulus in any point of a transverse section along the hull girder is given, in m³, by the following formula:

$$Z_A = \frac{I_Y}{|z - N|}$$

where:

- I_Y : Moment of inertia, in m⁴ of the transverse section considered, calculated taking into account [1.2.2] and all the continuous structural elements of the hull contributing to the longitudinal strength as defined in [3.1], with respect to the horizontal neutral axis
- z : Z co-ordinate, in m, of the considered point in the transverse section above the base line
- N : Z co-ordinate, in m, of the centre of gravity of the transverse section, above the base line.

3.2.2 Section moduli at bottom and deck

The section moduli at bottom and deck are given, in m³, by the following formulae:

- at bottom:

$$Z_{AB} = \frac{I_Y}{N}$$

- at deck:

$$Z_{AD} = \frac{I_Y}{V_D}$$

where:

- I_Y, N : Defined in [3.2.1]
- V_D : Vertical distance, in m, equal to:

  $V_D = z_D - N$
- z_D : z co-ordinate, in m, of the deck, above the base line.

3.3 Overall stresses

3.3.1 Overall stresses

a) General case:

The overall bending and shear stresses, in N/mm², in any point of a transverse section of a member contributing to the longitudinal and/or transversal global strength is obtained by the following formula:

$$\sigma_A = \frac{M_V}{Z_A} 10^{-3}$$

$$\tau_A = \frac{Q_v S_v V}{I_y t}$$

where:

- M_V, Q_v : Overall bending moments, in kN.m, and shear forces, in kN, induced by the loading cases considered combined as defined in Ch 3, Sec 2, [3]
- Z_A : Section modulus, in m³, calculated according to [3.2].
- S_v : Vertical section, in m², located above the point considered in the section taking into account [1.2.2]

V : Vertical distance, in m, between the centre of gravity of the vertical section S_v and the centre of gravity of the whole transverse section

I_y : Moment of inertia, in m^4 as defined in [3.2.1]

t : Thickness, in mm, of the element where the shear stress is calculated.

b) Overall stress for element other than steel:

For element other than steel, the stresses σ_A and τ_A calculated according to a) are to be corrected by the ratio between the Young modulus of the considered element and the steel Young modulus taken equal to $2{,}06.10^5$ N/mm^2 for σ_A, and by the ratio between the Shear modulus of the considered element and the steel Shear modulus taken equal to $7{,}93.10^4$ N/mm^2.

c) Simplified method for the calculation of the shear stress:

When the inertia of a section is not determined, the shear stress in a section may be calculated as follow:

- the total shear section S_A of the section may be considered as equal to the sum of the vertical sections of the:
  - for longitudinal strength analysis: Side shells and longitudinal bulkheads contributing to the global strength of the hull girder
  - for transversal strength analysis of catamaran: Transversal bulkheads contributing to the global strength of the platform.
- the shear stress may be taken equal to:

$$\tau_A = \frac{Q_v}{S_A} 10^{-3}$$

- Where a member is made in material other than steel with a shear modulus G equal to $7{,}93.10^4$ N/mm^2, the steel equivalent thickness that may be included for the calculation of the section S_A of the considered section is obtained, in mm, from the following formula:

$$t_{SE} = \frac{G}{7,93 \cdot 10^4} t_M$$

where:

t_M : Thickness, in mm, of the member under consideration

G : Shear modulus, in N/mm^2, of the considered member.

The shear stresses τ_A are to be corrected by the ratio between the shear modulus of the considered element and the steel shear modulus taken equal to $7{,}93.10^4$.

4 Calculation of global strength for multihull

4.1 General

4.1.1 Global strength approach for multihull

The global strength of multihull is to be successively examined:

- in head sea conditions, according to Article [3]
- In quartering sea conditions: By combining the stress analysis carried out in head sea conditions according to [3], considering only the bending moment in still water conditions, and in quartering sea conditions according to [4.3.4] b) combined as defined in Ch 3, Sec 2, [3]
- in digging in waves conditions, according to [4.3] b)
- in addition for swath, in transverse bending moment, according to [4.4].
- in addition for planing hull, according to [4.5]

The global strength of multihull having more than two floats is to be examined on a case-by-case basis.

4.2 Global strength in head sea condition

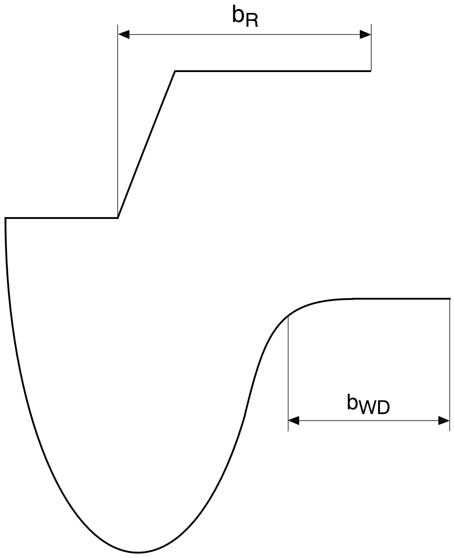
4.2.1 General

The global strength in head sea condition is to be checked as defined in Article [3].

The moment of inertia I_Y is to be calculated for only one float. A platform extending in length over at least 0,4 L_{WL} is to be considered for the calculation of the inertia of the float with a breadths b_R and b_{WD} as defined in Fig 1, limited to 10% of the platform longitudinal length.

For swath, struts extending in length over at least 0,4 L_{WL} is to be considered for the calculation of the inertia of the float.

Figure 1 : Hull girder strength Areas to be taken into account for continuous members (plates and stiffeners)



4.3 Global strength in quartering sea and in digging in waves

4.3.1 General

The global strength of multihull in quartering sea is to be examined according to:

- the present sub article for multihull built in steel material
- the present sub article and NR561 Aluminium Ships for multihull built in aluminium alloys
- the present sub article and NR546 Composite Ships for multihull built in composite materials.

The global strength analysis may be carried out by a beam model as shown in Fig 2, taking into account the bending and shear stiffness of the primary transverse cross structure of the platform and of one float.

The transverse cross beams are fixed in the model in way of the inner side shell of the other float.

Any other justified global analysis submitted by the Designer may be considered.

4.3.2 Primary transverse cross structure model

Each primary transverse cross structure in the platform is considered as a beam in the global model, taking into account:

- its bending inertia about an horizontal axis (depending mainly on the web height of the transverse cross beam or bulkhead, and the thickness of the bottom and deck platform
- its vertical shear inertia (depending on the web height of the transverse cross beams or bulkheads and their thickness)
- its span between inner side shell of floats.

4.3.3 Float model

The float is modelled as a beam having, as far as practicable:

- vertical and horizontal bending inertia, and
- a shear inertia, and
- a torsional inertia about longitudinal float axis

close to the actual float values.

4.3.4 Loading of the model

The two following loading cases are to be considered:

a) Loads in quartering sea condition as shown on Fig 3, where the torsional moment exerted on the platform and induced by encountered waves in quartering sea is represented by two vertical forces F defined in Ch 3, Sec 2, [5.3.2].

Note 1: As a general rule, two successive loading cases are to be taken into account: the case as shown in Fig 3 and the same case with forces in opposite direction.

b) Loads in digging in waves condition as shown on Fig 4, where the torsional moment induced by the digging in wave is represented by the vertical linear forces F_{VD} and horizontal linear forces F_{HD}, in kN/m, equal to:

$F_{VD} = F_{vm} - F_{vl}$

$F_{HD} = F_{hm} - F_{hl}$

where:

F_{vm}, F_{vl}, F_{hm}, F_{hl}: Fore float loads defined in Ch 3, Sec 2, [6.2.1] b)

The vertical and horizontal linear loads F_{VD} and F_{HD} are to be applied from the fore part of the modelled float on a distribution length, in m, equal to L_{WL} / 4 without being taken greater than d, where:

L_{WL} : Length at waterline at full load, in m

d : Length, in m, of digging in wave, equal to the distance between the extreme fore end of each float and the forward part of the platform.

4.3.5 Main structure check

The global bending moments and shear forces distribution in the float are as shown in Fig 5, and in the primary transverse cross structure as shown in Fig 6.

The bending stresses σ_A and the shear stresses τ_A in the float and in the platform of the multihull are to be directly deduced from the beam model calculation and are to be in compliance with the criteria defined in Article [2].

For the primary transverse cross structure, the bending stresses and shear stresses are to be calculated in way of the modelled float.

Particular attention is to be paid to:

- shear buckling check of cross bulkheads
- compression/bending buckling check of platform bottom and platform deck platings in areas where the bending moment is maximum.

Figure 2 : Model principle

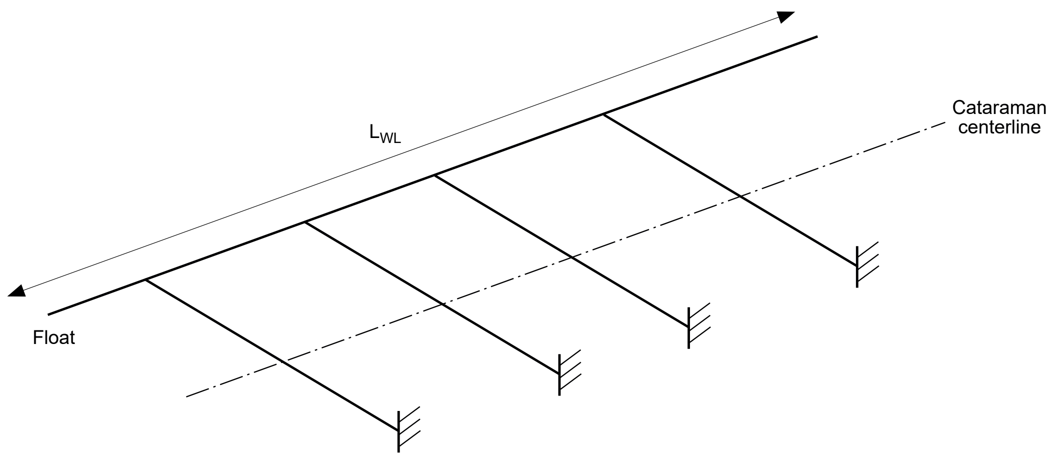


Figure 3 : Primary transverse cross structure of multihull - Loading in quartering sea condition

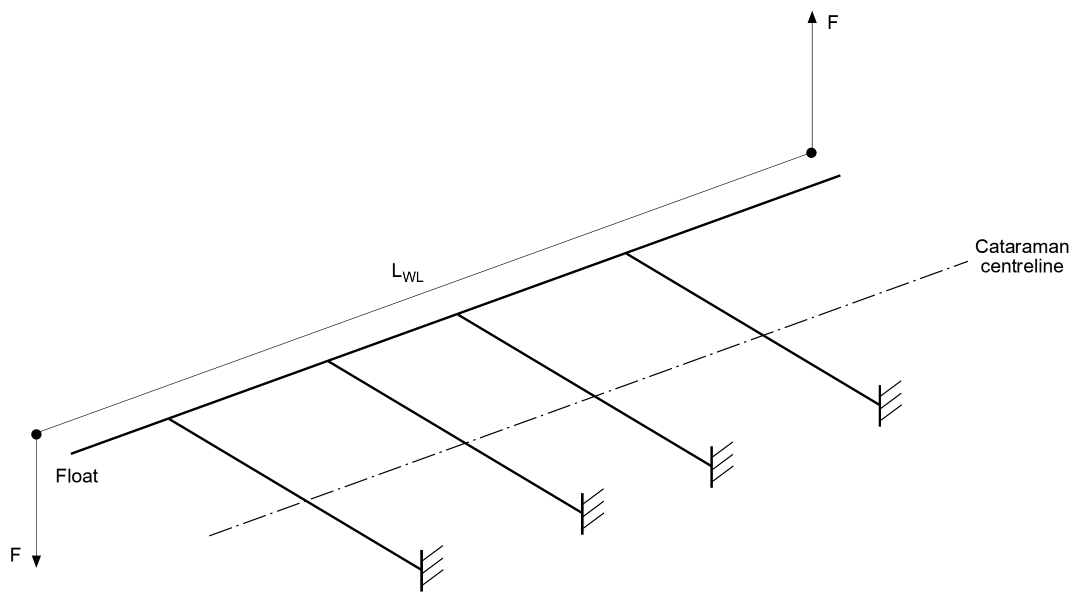


Figure 4 : Primary transverse cross structure of multihull - Loading in digging in wave condition

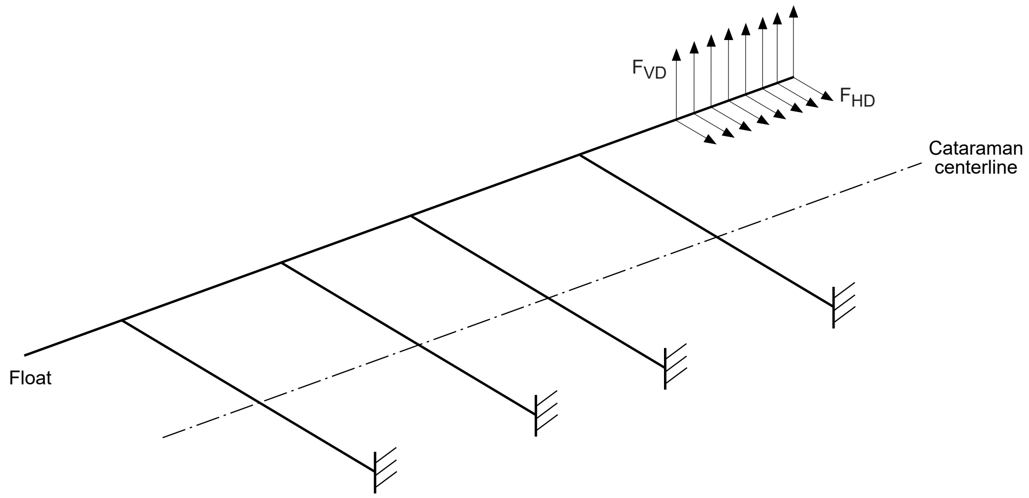


Figure 5 : Longitudinal distribution of the bending moment and shear force along the float

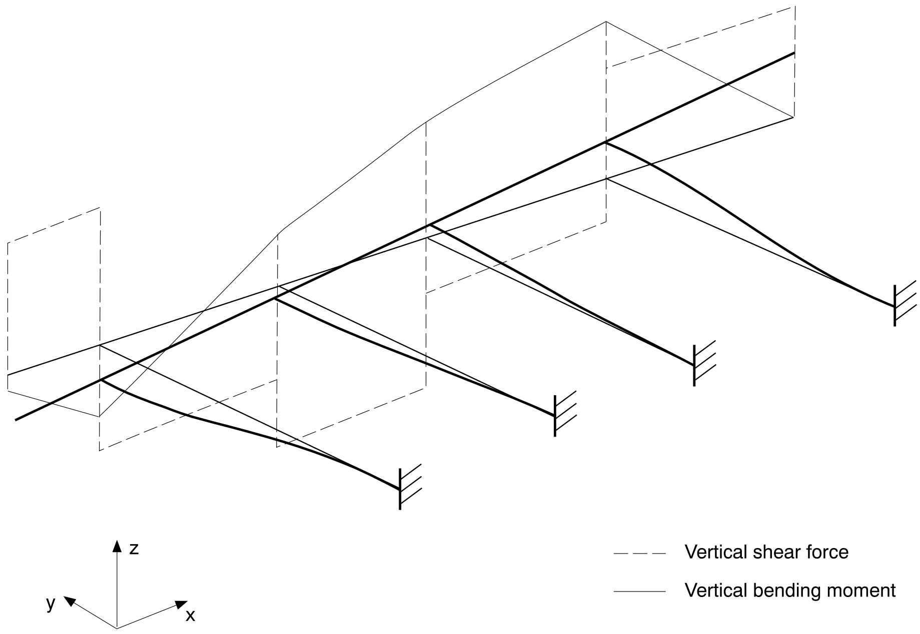
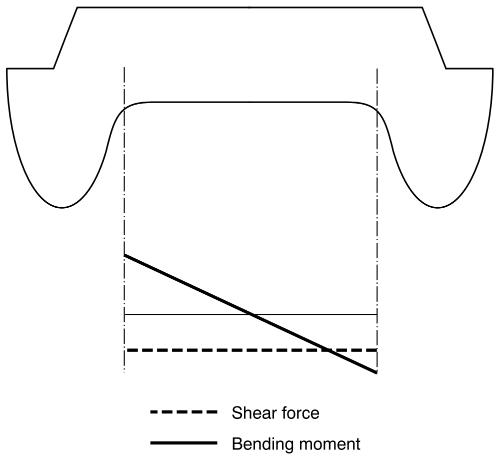


Figure 6 : Transverse distribution of bending moments and shear forces



4.4 Transverse bending moment acting on twin-hull connections of swath

4.4.1 The global transversal strength analysis of the primary structure of the platform of swath is to be carried out by a direct calculation.

The bending moment M_Q, in kN.m, and the shear force F_Q, in kN, applied along the platform structure of swath is to be taken equal to:

$M_Q = h_M \cdot F_Q$

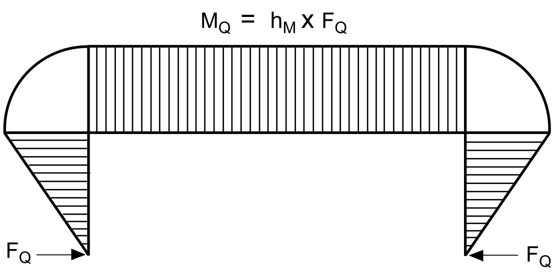
where:

h_M : Half the draught T, in m, plus the distance from the waterline at draught T to the midpoint of the platform structure (see Ch 3, Sec 2, Fig 5)

F_Q : Beam side force, in kN, defined in Ch 3, Sec 2, [6.2.2].

The bending moment distribution is to be as shown on Fig 7. The shear force is to be considered as constant along the struts of the swath.

Figure 7 : Bending moment distribution



4.5 Global strength for planing hull

4.5.1 The global strength analysis of multihull planing hull is to be carried out:

a) In head sea condition:

according to [3.3] taking into account:

- Bending moments and shear forces defined in Ch 3, Sec 2, [6.1.1]
- A section modulus based on a moment of inertia I_Y calculated for only one float. A platform extending in length over at least 0,4 L_{WL} is to be considered for the calculation of the inertia of the float with a breadths b_R and b_{WD} as defined in Fig 1, limited to 10% of the platform longitudinal length.

b) In quartering sea conditions:

according to [4.3], in quartering sea only, taking into account the minimum transverse torsional moment along the float and in the platform defined in Ch 3, Sec 2, [6.1.2].

5 Global strength analysis for monohull and catamaran by finite element calculation

5.1 General

5.1.1 This Article is a guidance for the stress check (maximum and buckling stresses) of hull girder and platform structure loaded under global hull girder loads only using a finite element complete ship model.

5.2 Steel and aluminium structure

5.2.1 Structural model

a) General:

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

Long superstructures are to be modeled in order to also reproduce the correct hull global strength, in particular the contribution of each superstructure deck to the hull girder longitudinal strength.

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

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

The following structural elements may be disregarded:

- small deck openings (less than typical size of elements)
- openings in webs of primary supporting members when their height is less than 50% of the web height, provided that a detailed analysis is performed for the assessment of these primary supporting members according to Sec 5, [3.2].

b) Finite elements:

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

Shell elements are to be used to represent plating. As a rule, the aspect ratio of shell elements is generally not to be greater than 2, and in no case greater than 4.

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

Ordinary stiffeners are to be modeled with bar elements and may be grouped at regular intervals.

Webs of primary structure are to be modeled with shell elements.

Face plates of primary structure may be modeled with rod or bar elements.

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

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

5.2.2 Loads distribution

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

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

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

Hull girder load distributions are to target the bending moments and shear forces distributions defined in Ch 3, Sec 2.

Detailed justifications of the loading distributions may be requested by the Society to verify the values of the actual global bending moments and shear forces applied to the model.

5.2.3 Boundary conditions

The finite element calculation is to be performed with displacement restrictions applied to nodes of the model. Rotations of these nodes are to be free.

As a rule, these nodes are to be located outside the model areas where global stress checks are carried out.

Detailed justifications may be requested by the Society to verify that the forces reactions applied to these nodes do not affect the global bending moments and shear forces applied to the model.

5.2.4 Stress check

a) Stress components:

Stress components are generally identified with respect to the element co-ordinate system. The orientation of the element co-ordinate system in relation to the reference co-ordinate system of the model is to be specified.

The following stress components to be considered and calculated at the centroid of each element are:

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

b) Stress check

The maximum stresses and buckling stresses are to be calculated as follow:

- Maximum stress check:

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

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

  Where σ_1, σ_2 and τ_{12} are defined in b).

- Buckling stress check:

  Where the buckling panel is meshed by several finite plate elements, the stresses of the buckling panel are obtained by the following methodology:

  - For each plate finite element, the stresses ($\sigma_{\xi\varepsilon}{}^*$, $\sigma_{\psi\varepsilon}{}^*$, $\tau_\varepsilon{}^*$) expressed in the element co-ordinate system are projected in the co-ordinate system of the buckling panel to obtained the stresses ($\sigma_{\xi\varepsilon}$, $\sigma_{\psi\varepsilon}$, τ_ε).
  - For the buckling panel, the stresses are calculated according to the following formula:

$$\sigma_x = \frac{\sum_i^n A_i \sigma_{x\,e_i}}{\sum_i^n A_i} \geq 0$$

$$\sigma_y = \frac{\sum_i^n A_i \sigma_{y\,e_i}}{\sum_i^n A_i} \geq 0$$

$$\tau = \frac{\sum_i^n A_i \tau_{e_i}}{\sum_i^n A_i} \geq 0$$

where:

$\sigma_{\xi\,\varepsilon\iota}$, $\sigma_{\psi\,\varepsilon\iota}$: Stresses, in N/mm², of the plate finite element i, taken equal to 0 in case of tensile stress

τ_{ei} : Shear stress, in N/mm², of the plate finite element i

A_i : Area, in mm², of the plate finite element i.

5.2.5 Scantling criteria

The maximum actual stresses and buckling stresses are to fulfill the permissible global stresses and buckling safety factors defined in Ch 2, Sec 3, Tab 1 taking into account Ch 2, Sec 3, [2.3].

5.3 Composite structure

5.3.1 General

The structural model, the global loads distribution and the boundary conditions are to fulfill the general requirements defined in [5.2].

5.3.2 Stress check

The stress check is to be carried out as defined in Ch 2, Sec 3, [3.1].

5.3.3 Scantling criteria

The rule safety factors to be considered are defined in Ch 2, Sec 3, [3.2] taking into account Ch 2, Sec 3, [3.2.1] c).