# 2024

# Guideline of Structural Assessment for Liquefied Gas Carriers with Type A Prismatic Tanks

GL-0044-E

KR



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## APPLICATION OF

## "Guideline of Structural Assessment for Liquefied Gas Carriers with Type A Prismatic"

1. Unless expressly specified otherwise, the requirements in the Guideline apply to ships for which are contracted for construction are signed on or after 1 July 2024.

# CONTENTS

# Chapter 1

# General Principles

# Section 1 – Application

## 1. Scope of application

### 1.1. General

#### 1.1.1.

This **Guideline** applied to the following ships:

a) Ships intended to be registered and classed as "Liquefied Gas Carrier" with independent type A prismatic tanks having a length *L* of 150 m above and:

b) Being self-propelled ships with unrestricted navigation.

c) Cargo hold region as defined in **Pt 15, Ch 1, Sec 1, [2.4] of Rules for the Classification of Steel Ships.**

d) Note 1: Type A prismatic tanks mean that the ship has independent tanks (**1A** notation assigned) as a cargo containment system in hold for the carriage liquefied gases in bulk in accordance with **Pt 7, Ch 5 of Rules for the Classification of Steel Ships.**

#### 1.1.2. Relation with Part 15 of Rules for the Classification of Steel Ships

Ships are to comply with the principles and requirements of **Part 15 of Rules for the Classification of Steel Ships** except for the requirements specified in this **Guideline.** Especially, this **Guideline** supersedes or replaces the requirements of **Part 15** for hull scantlings and direct strength assessment.

#### 1.1.3. Relation with Part 3 of Rules for the Classification of Steel Ships

Ships are to comply with the principles and requirements of **Part 3 of Rules for the Classification of Steel Ships** except for the requirements specified in this **Guideline**. Especially, this **Guideline** supersedes or replaces the requirements of **Part 3** for hull scantlings and direct strength assessment.

#### 1.1.4. Novel designs

Ships with novel features or unusual hull design are to comply with **Pt 15, Ch 1, Sec 3, [6.2] of Rules for the Classification of Steel Ships.**

### 1.2. Structure parts not covered by this Guideline

#### 1.2.1.

Designer should take care that parts of the structure that this **Guideline** does not cover comply with the relevant requirements of the Society's **Rules**.

### 1.3. Application and implementation of this Guideline

#### 1.3.1.

This Guideline addresses the hull structural aspects of classification and does not include requirements related to the verification of compliance with the **Rules** during construction and operation.

### 1.3.2.

The Society verifies compliance with the classification requirements and the applicable international regulations when authorized by a Nation Administration during design, construction and operation of the ship.

# Section 2 – Design Basis

## 1. General

### 1.1. Internal environment

#### 1.1.1. Products as cargoes

The **Guideline** is based on the design temperature of the cargo is between −10 ℃ and −55 ℃, which is to be assumed as the cargo temperature as atmospheric pressure. The density and boiling temperature of cargoes typically loaded in type A prismatic tanks are listed in for reference. The design temperature and density of cargoes at its temperature shall be appropriately specified by designer.

As LPG (Liquefied Petroleum Gas) is a mixture of hydrocarbon gases, most commonly propane, butane and propylene, the cargo density can be different depending on composition ratio of the mixture.

**Table 1 List of products as liquefied cargoes between −10 ℃ and −50 ℃**

| Product Name | Chemical formula | Density (t/m$^3$) | Boiling point (℃) atm |
|---|---|---|---|
| Ammonia, anhydrous | $NH_3$ | 0.68 | -33.3 |
| Dimethyl Ether (DME) | $CH_3OCH_3$ | 0.73 | -24.8 |
| Propane | $C_3H_8$ | 0.58 | -42.3 |
| Propylene | $C_3H_6$ | 0.61 | -47.6 |
| Vinyl Chloride (VCM) | $CH_2CHCL$ | 0.97 | -13.4 |

### 1.2. Hull structure as a secondary barrier

#### 1.2.1. Extension of secondary barrier

The hull structure is to be designed as a secondary barrier with extension as shown in Figure 1. The equivalent level in a cargo hold is the flooded liquid cargo level in a state of leakage assuming upright static condition. The secondary barrier shall be extended not less than 500 mm from the static 30° heeled equivalent level.

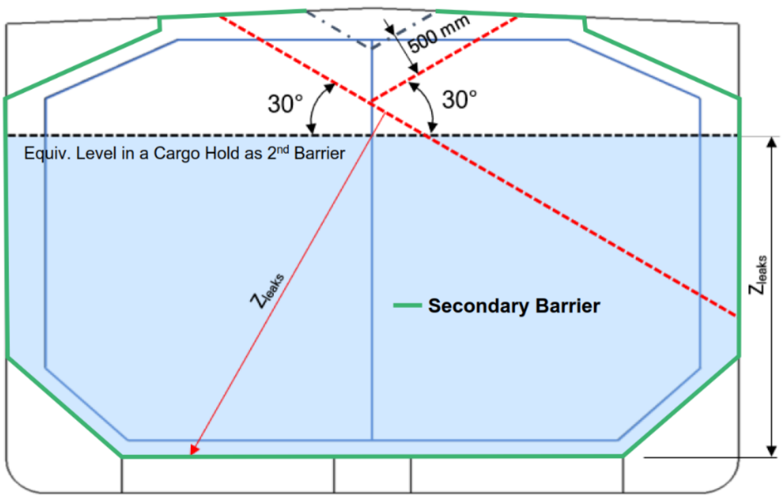



Figure 1 Secondary barrier extent

## 1.3. Supports of independent cargo tanks

### 1.3.1. Typical supports structure

All degrees of freedom for cargo tanks are typically constrained by four types of support structures as listed in **Table 2**. In such a support structure as shown in **Figure 2**, a spacer made of wooden block is installed between cargo tanks and support structure so that the low cargo temperature is not transmitted to hull structure. The spacer is fixed to the tank or the support structure so as not to fall off with an adhesive such as Resin, and only contact occurs on the opposite surface of the adhesive surface without the adhesive.

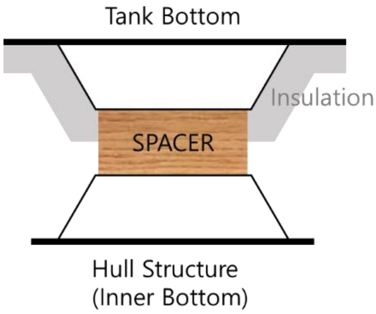



Figure 2 **Typical vertical tank support structure**

**Table 2 Support types and their constrained roles**

| Supports types (◈: main role ◇: naturally accompanied role) | Constrained in | | | | | |
|---|---|---|---|---|---|---|
| | Translation | | | Rotation | | |
| | $\delta_X$ | $\delta_Y$ | $\delta_Z$ | $\theta_X$ | $\theta_Y$ | $\theta_Z$ |
| Vertical Support | ◇[1)] | ◇[1)] | ◈(downward) | ◇ | ◇ | ◇[1)] |
| Anti-rolling Support | - | ◈ | - | ◇ | - | ◇ |
| Anti-pitching Support | ◈ | - | - | - | - | - |
| Anti-floating Support | -[2)] | -[2)] | ◈(upward) | -[2)] | -[2)] | -[2)] |

[1)]: By friction force

[2)]: Assume open (not contact) state in normal condition.

### 1.3.2. Vertical supports

Vertical structures are installed evenly on inner bottom to prevent tank movement in vertical direction as well as to support tank self-weight and cargo weight. These support structures naturally also serve to prevent rotation naturally in the longitudinal and transverse directions by friction force. Due to hull deformation and rotational motion, a reaction force acts more on outer peripheric supports generally. Schematic view of a typical vertical support is shown in **Figure 2**.

### 1.3.3. Anti-rolling support

To prevent lateral movement due to longitudinal rotation, anti-rolling supports are installed in the same longitudinal position on the upper and lower surfaces of the tank. If not installed in the same longitudinal direction, there is room for distortion of the tank itself. Two or more points are installed commonly in the longitudinal direction to constrain the rotation in the Z direction in the global coordinate system. Typical configuration of this support is shown in **Figure 3**.

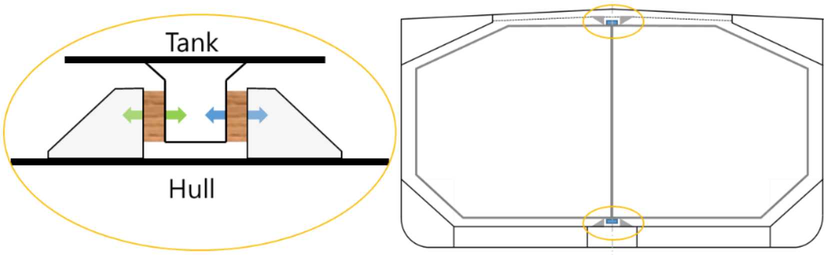



Figure 3 **Schematic view of anti-rolling supports**

### 1.3.4. Anti-pitching support

Two structures are installed in each tank for the dispersion of force in the longitudinal or transverse direction as structures for restraining a tank movement due to collision acceleration according to the requirements of the **IGC Code**. The structural configuration is similar to the anti-rolling support structure, and each support structure is designed to take only compression force.

### 1.3.5. Anti-floating support

In the case of this support structure, it constrains the upward motion in the Z direction in the Global coordinate system. Like vertical supports, it is common designs to be evenly installed on the upper slanted tank top so that the load acts evenly on the tank surface. Due to the nature of the tank shape and member arrangement, it is often characterized by a mixture of Rugs for the installation of independent tanks in the assembly stage.

### 1.3.6. Spacer

As a component of support structures, a wooden spacer is generally designed to receive only compression. Depending on the support arrangement, shearing force may be applied considerably. For this case, it is necessary to consider shear force so that it is designed with sufficient strength.

### 1.3.7. Friction between spacer and steel

A frictional force between the wooden spacer and steel may act on a surface without adhesive, and such frictional force shall be considered when obtaining a reasonable reaction force of each support structure. It is known that the size of the friction force varies depending on the moisture content of the spacer in the state of the contact surface (approximately roughness), and the size of the friction force in a stationary state and in a moving state is different. Considering that very dry inert gas is normally circulated in the inter barrier space between the hull and the tank, it would be reasonable to use the frictional force in a dry state. The coefficient of kinetic and static friction between wooden spacer and steel plate is 0.15 and 0.3 respectively, if not specified otherwise by designer.

# 2. Corrosion addition

## 2.1. Applicability

### 2.1.1.

Unless otherwise specified, the net thickness of a structural element is required for structural strength in compliance with **Ch 3, Sec 2 of Part 15 of Rules for the Classification of Steel Ships**.

## 2.2. Corrosion addition

### 2.2.1.

The determined corrosion addition for a typical midship section except the case as stated in **[2.2.2]** is shown in Figure 4.

### 2.2.2.

When the ships are built for LPG carrying purpose only, the reserve thickness ($t_{res}$) of the LPG cargo tank can be taken as 0.0 mm.

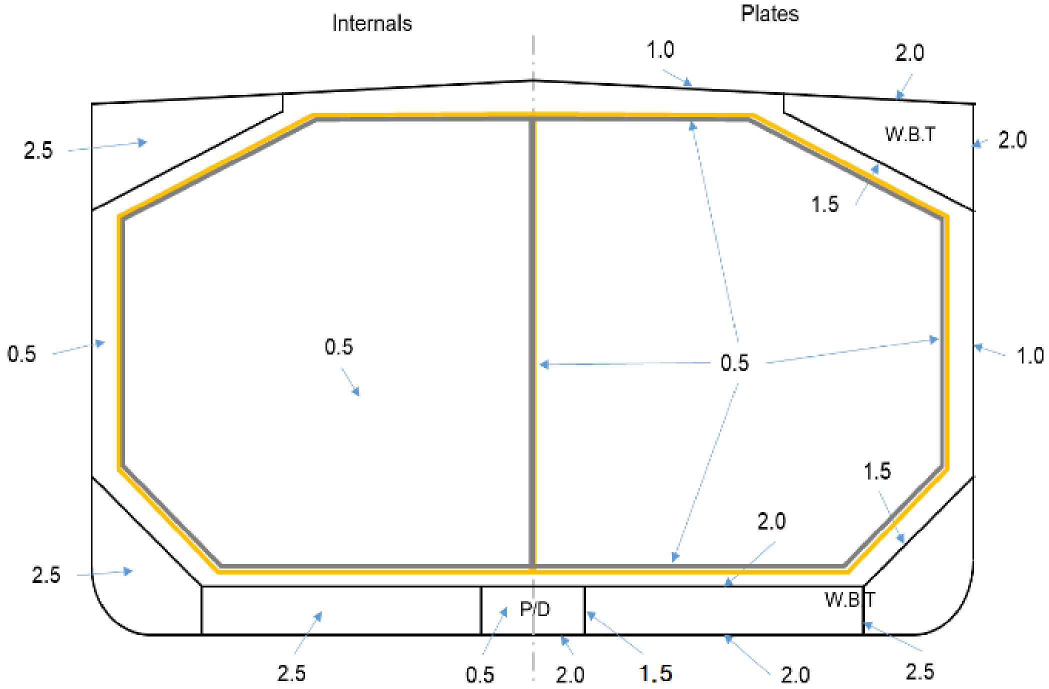



Figure 4 Corrosion addition for a typical midship

# Chapter 2

# Hull Girder Ultimate Strength

# Section 1 – Hull Girder Ultimate Strength

## 1. Application

### 1.1. General

#### 1.1.1.

The hull girder ultimate strength is to be assessed through the cargo hold region and machinery space.

#### 1.1.2.

The hull girder ultimate bending capacity is to be checked to ensure that it satisfies the checking criteria given in [2]. Such checking criteria are applicable to intact ship structures in seagoing conditions.

## 2. Checking criteria

### 2.1. General

#### 2.1.1.

The vertical hull girder ultimate bending capacity at any hull transverse section is to satisfy the following criteria:

$$M \le \frac{M_U}{\gamma_R}$$

where,

$M$ : Vertical bending moment, in $kNm$, to be obtained as specified in [2.2.1].

$M_U$ : Vertical hull girder ultimate bending capacity, in $kNm$, to be obtained as specified in [2.3].

$\gamma_R$ : Partial safety factor for the vertical hull girder ultimate bending capacity to be taken equal to:

$\gamma_R$=1.1

### 2.2. Hull girder ultimate bending loads

#### 2.2.1.

The vertical hull girder bending moment, $M$ in hogging and sagging conditions, to be considered in the ultimate strength check is to be taken as:

$$M = \gamma_S M_{sw} + \gamma_W M_{wv}$$

where,

$M_{sw}$ : Still water bending moment, in $kNm$, in hogging and sagging conditions.

$M_{wv}$ : Vertical wave bending moment, in $kNm$, in hogging and sagging conditions

$\gamma_S$ : Partial safety factor for the still water bending moment

$\gamma_S$=1.0

$\gamma_W$ : Partial safety factor for the vertical wave bending moment

$\gamma_W$=1.2

The ultimate strength criteria are based on the net scantlings approach, applying corrosion addition as defined in Ch 1, Sec 2, [2.2].

## 2.3. Hull girder ultimate bending capacity

### 2.3.1.

The ultimate bending moment capacities of a hull girder transverse section, in hogging and sagging conditions, are defined as the maximum values of the curve of bending moment capacity versus the curvature $\chi$ of the transverse section considered (see Figure 1). The curvature $\chi$ is positive for hogging condition and negative for sagging condition.

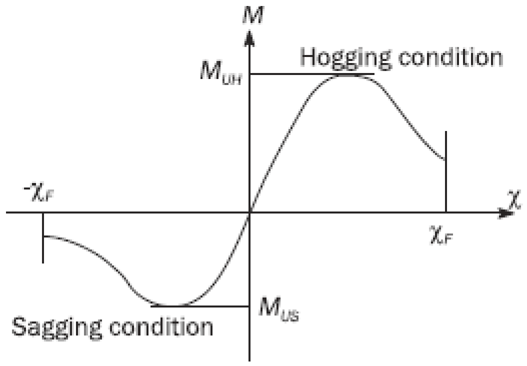



Figure 1 Bending moment capacity versus curvature $\chi$

The hull girder ultimate bending capacity, $M_U$, is to be calculated according to [2.4].

## 2.4. Hull girder ultimate capacity

### 2.4.1.

The hull girder ultimate capacity is to be assessed by the principles and requirements of **Pt 13, Ch 5, Appendix 2 of Rules for the Classification of Steel Ships**.

# Chapter 3
# Loads

# Section 1 – Ship motions and accelerations

## 1. Ship motions and accelerations

### 1.1. Ship motions

#### 1.1.1. Roll motion

$K_r$ and $GM$ for calculating roll motion, are to be taken as defined in **Table 1** unless provided in the loading manual.

**Table 1 $k_r$ and $GM$ values**

| Loading condition | $T_{LC}$ | $k_r$ | GM |
|---|---|---|---|
| Full load condition | $T_{SC}$ | $0.35B$ | $0.09B$ |
| Ballast condition | $T_{BAL}$ | $0.45B$ | $0.20B$ |

# Section 2 – Internal Loads

## 1. Pressure due to liquids

### 1.1. Static pressure in accidental condition

#### 1.1.1. Static pressure in a state of cargo tank leakage

The static pressure, $P_{leaks}$ in kN/m$^2$, for hull structure as a secondary barrier in envisaged cargo tank leakage is to be taken as:

$$P_{leaks} = \rho_L g z_{leaks}$$

where:

$\rho_L$ : Density of liquid in cargo tank, in t/m$^3$.

$z_{leaks}$ : Largest load height above the LCP where the pressure is to be determined measured from boundary of secondary barrier in m, when the primary barrier is failed. The 30° static heel shall be considered.

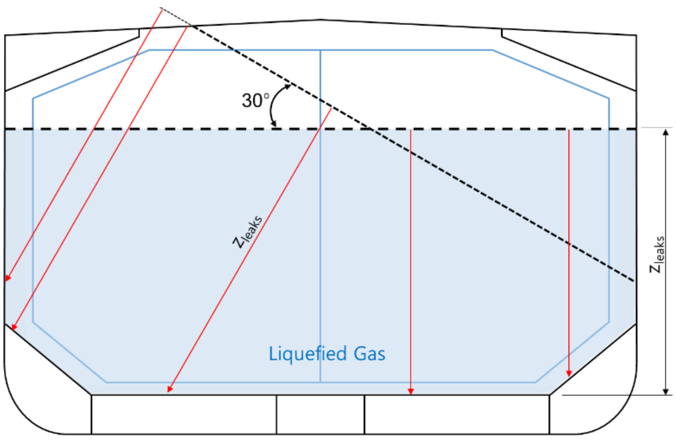



Figure 1 Determination of liquid height $z_{leaks}$

#### 1.1.2. Static pressure in flooded cargo hold

The static pressure, $P_{fs}$ in kN/m$^2$, for watertight boundaries of cargo hold is to be taken as:

$$P_{fs} = \rho g (z_{FD} - z)$$

where:

$z_{FD}$ : Z coordinate, in m, is to be taken as 0.85$D$.

## 2. Sloshing pressure in tanks

### 2.1. Assumption

#### 2.1.1.

The sloshing pressure is to be assessed by the principles and requirements of **Pt 13, Ch 4, Sec 6 of Rules for the Classification of Steel Ships**, is to be taken as follows:

- Minimum sloshing pressure, as defined in **Pt 13, Ch 4, Sec 6 [6.2]**

- Sloshing pressure due to longitudinal liquid motion, as defined in **Pt 13, Ch 4, Sec 6 [6.3]**, see Figure 2 and Figure 3, Figure 4
- Sloshing pressure due to transverse liquid motion, as defined in **Pt 13, Ch 4, Sec 6 [6.4]**, see Figure 5

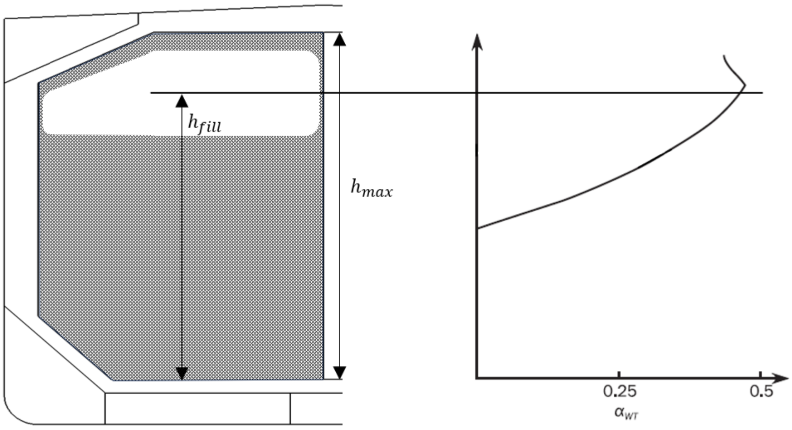



Figure 2 Transverse wash bulkhead coefficient

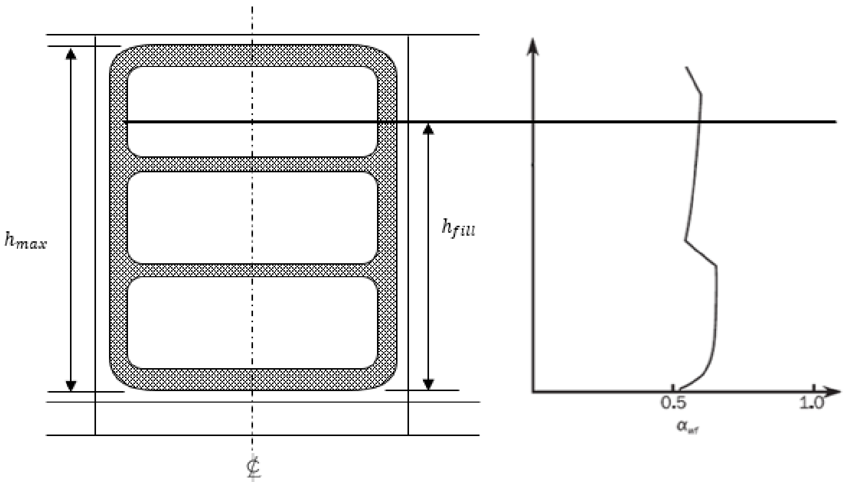



Figure 3 Transverse web frame coefficient

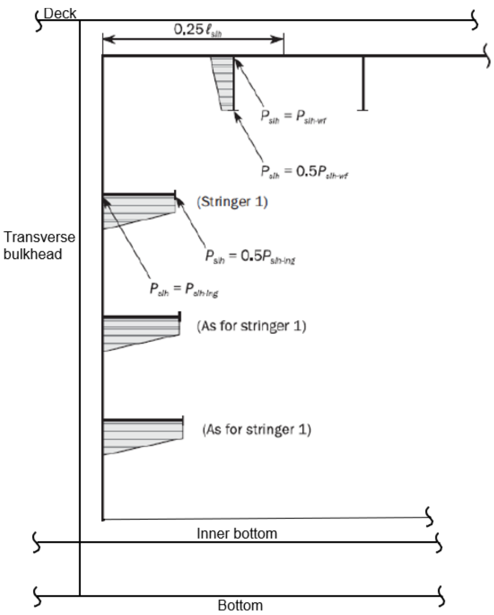



Figure 4 Sloshing pressure distribution on transverse stringers and web frames

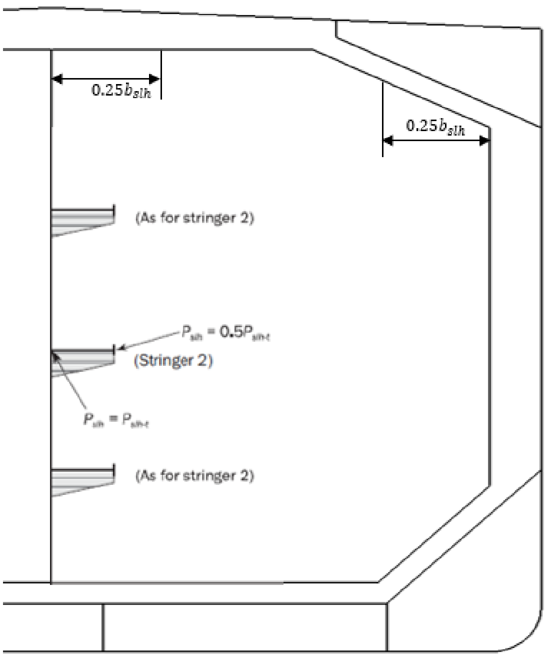



Figure 5  Sloshing pressure distribution on longitudinal stringers and girders

# Chapter 4

# Hull Local Scantling

# Section 1 – Load Application

## 1. Load combination

### 1.1. Lateral pressure

#### 1.1.1. Lateral pressure in state of tank leakage

Secondary barriers of cargo containment are to be subjected to lateral pressure in a leakage state of tank.

## 2. Design load sets

### 2.1. Application of load components

#### 2.1.1. Application

These requirements apply to:

a) Plating and stiffeners along the cargo hold area of the ship
b) PSM in cargo tanks

#### 2.1.2. Design load sets for plating, stiffeners and PSM

Design load sets for plating, stiffeners and primary supporting members are given in Table 1.

Table 1 **Design load sets**

| Item | Design load set | Load component | Draught | Design load | Acceptance criteria | Loading condition |
|---|---|---|---|---|---|---|
| External shell and Exposed deck | SEA-1 | $P_{ex}$, $P_D$ | $T_{SC}$ | S+D | AC-SD | Full load condition |
| | SEA-2 | $P_{ex}$ | $T_{SC}$ | S | AC-S | Harbour condition |
| Water ballast tank | WB-1 | $P_{in} - P_{ex}$ | $T_{BAL}$ | S+D | AC-SD | Ballast condition |
| | WB-2 | $P_{in} - P_{ex}$ | $T_{BAL}$ | S+D | AC-SD | Ballast exchange condition |
| | WB-3 | $P_{in} - P_{ex}$ | $T_{BAL}$ | S | AC-S | Harbour condition |
| | WB-4 | $P_{in} - P_{ex}$ | $0.4T_{SC}$ | T | AC-T | Tank test condition |
| Independent cargo tank | CT-1 | $P_{in}$ | $0.7T_{SC}$ | S+D | AC-SD | One cargo tank loaded |
| | CT-2 | $P_{in}$ | - | S | AC-S | Harbour condition |
| | CT-3 | $P_{in}$ | - | T | AC-T | Tank test condition |
| | COL | $P_{in}$ | - | A | AC-A | Collision condition |
| Cargo hold area as secondary barrier | LK | $P_{in}$ | - | S | AC-A | Leakage state |
| Compartment not carrying liquid | FD | $P_{in}$ | 0.85D | S | AC-A | Flooded condition |

# Section 2 – Plating

## 1. Plating subjected to lateral pressure

### 1.1. Yielding check

#### 1.1.1. Plating of cargo tank due to pressure by IGC acceleration

The net thickness of tank shell as a cargo containment system, t in mm, is not to be taken less than:

$$t = 0.0158\alpha_p b\sqrt{\frac{P_{IGC}}{C_{a-IGC}R_{eH}}}$$

where:

$C_{a-IGC}$ : Permissible bending coefficient for plate taken equal to

$$C_{a-IGC} = {}^{1}/_{1.2}$$

#### 1.1.2. Plating of cargo tank for collision condition

The net thickness of tank shell for collision condition, t in mm, is not to be taken less than:

$$t = 0.0158\alpha_p b\sqrt{\frac{P_{Col}}{R_{eH}}}$$

where:

$P_{Col}$ : $P_{ls} + P_{Col-x}$

$P_{ls}$ : Static pressure on the LCP of an EPP

$P_{Col-x}$ : pressure by collision acceleration required by IGC;0.5g forward or 0.25g aftward

# Section 3 – Stiffeners

## 1. Stiffeners subject to lateral pressure

### 1.1. Yielding check

#### 1.1.1. Web plating

The minimum net web thickness, $t_w$ in mm, is not taken less than the greatest value calculated all applicable design load sets as defined in **Ch 4, Sec 1, [2]**, given by **Pt 15, Ch 6, Sec 5, [1.1.1] of Rules for the Classification of Steel Ships** including the required net section modulus of stiffeners due to pressure by IGC acceleration with $C_t = 0.9$.

#### 1.1.2. Section modulus of stiffeners of cargo tank

The minimum net section modulus, Z in $cm^3$, is not taken less than the greatest value calculated all applicable design load sets as defined in **Ch 4, Sec 1, [2]**, given by **Pt 15, Ch 6, Sec 5, [1.1.2] of Rules for the Classification of Steel Ships** including the required net section modulus of stiffeners due to pressure by IGC acceleration as follows:

$$Z = \frac{P_{IGC} \cdot s \cdot l_{bdg}^2}{f_{bdg} \cdot \sigma_{All}}$$

Where:

$\sigma_{All}$ : Allowable stress by **IGC Code** taken as minimum of $R_m/2.66$ and $R_{eH}/1.33$

#### 1.1.3. Stiffeners of cargo tank for collision condition

The minimum net section modulus of stiffeners of cargo tanks, in $cm^3$, is not taken less than:

$$Z = \frac{P_{Col} \cdot s \cdot l_{bdg}^2}{f_{bdg} \cdot \sigma_{eH}}$$

Where:

$P_{Col}$ : $P_{ls} + P_{Col-x}$

$P_{ls}$ : Static pressure on the LCP of a stiffener

$P_{Col-x}$ : pressure by collision acceleration required by IGC; 0.5g forward or 0.25g aftward

### 1.2. Beam analysis

#### 1.2.1. Stress criteria

The stress is to comply with the following criteria for cargo tank structure.

a) $\sigma \leq R_{eH}/1.33$

# Section 4 – Primary Support Members and Pillars

## 1. Primary support members of cargo tank

### 1.1. Scantling requirements

#### 1.1.1. Net section modulus

The minimum net section modulus, Z in cm$^3$, of primary supporting members subjected to later pressure is not taken less than the greatest value calculated all applicable design load sets as defined in **Ch 4, Sec 1, [2]**, given by **Pt 15, Ch 6, Sec 5, [1.1.2] of Rules for the Classification of Steel Ships** including the required net section modulus of stiffeners due to pressure by **IGC** acceleration as follows:

$$\mathrm{Z} = \frac{P_{IGC} \cdot S \cdot l_{bdg}^2}{f_{bdg} \cdot \sigma_{All}}$$

Where:

$\sigma_{All}$ : Allowable stress by **IGC Code** taken as minimum of $R_m/2.66$ and $R_{eH}/1.33$

#### 1.1.2. Net shear area

The net shear area, $A_{shr-n50}$ in cm$^2$, of primary supporting members subjected to lateral pressure is not taken less than the greatest value calculated all applicable design load sets as defined in **Ch 4, Sec 1, [2]**, given by **Pt 15, Ch 6, Sec 6, [3.2.2] of Rules for the Classification of Steel Ships** including the required net section modulus of stiffeners due to pressure by **IGC** acceleration with $C_t = 0.9$.

# Section 5 – Single Side Structure

## 1. Single side structure

### 1.1. Strength criteria

#### 1.1.1. Net section modulus and net shear sectional area

The net section modulus $Z$, in cm$^3$, and the net shear sectional area $A_{shr}$, in cm$^2$, in the mid-span area of side frames subjected to lateral pressure are not to be taken less than:

$$Z = 0.405 \frac{Ps\ell_{SF}^2}{f_{bdg} C_{st} R_{eH}}$$

$$A_{shr} = 5.0 \frac{Ps\ell_{SF}}{C_{st}\tau_{eH}} \left( \frac{\ell_{SF} - 2\ell_B}{\ell_{SF}} \right) 10^{-3}$$

Where:

$f_{bdg}$ : Bending coefficient taken as 10.

$C_{st}$ : Permissible stress coefficient for the design load set being considered taken as:

$C_{st} = 0.75$ for acceptance criteria set AC-S.

$C_{st} = 0.90$ for acceptance criteria set AC-SD.

$\ell_B$ : Lower bracket length, in m, as defined in Figure 1.

$\ell_{SF}$ : Side frame span $\ell$, in m, as defined in Figure 2, not to be taken less than 0.25 D.

$P$ : Design pressures, in kN/m², for design load sets as defined in Ch 4, Sec 1, Table 1.

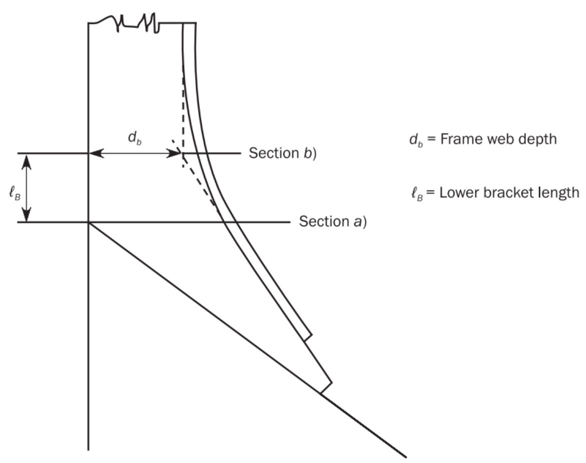



Figure 1 Side frame lower bracket length

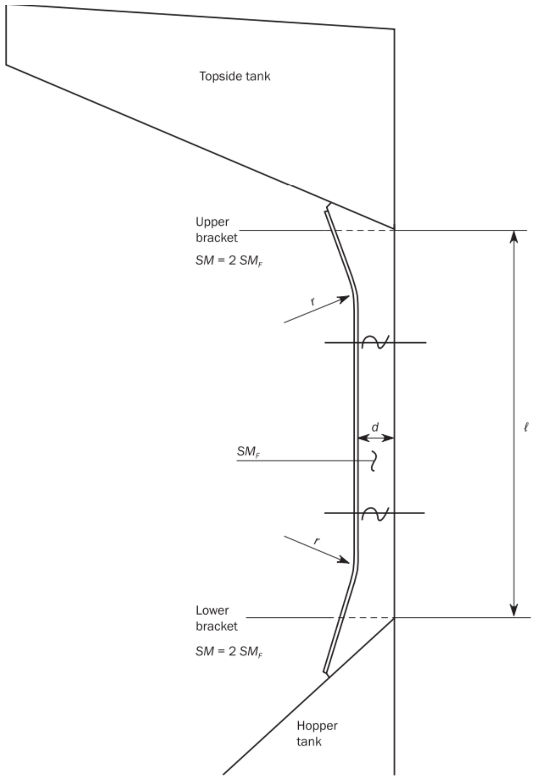



Figure 2 Dimensions of lower and upper brackets

### 1.1.2. Additional strength requirements

The net moment of inertia $I$, in cm$^4$, of the three side frames located immediately abaft the collision bulkhead is not to be taken less than:

$$Z = 0.18 \frac{P\ell_{SF}^4}{n}$$

Where:

$n$ : Frame number of considered side frame counted from the collision bulkhead to the frame in question, taken equal to 1, 2 or 3.

As an alternative, supporting structures, such as horizontal stringers, are to be fitted between the collision bulkhead and a side frame which is in line with transverse webs fitted in both the topside tank and hopper tank, maintaining the continuity of the forepeak stringers within the foremost hold.

## 1.2. Lower bracket of side frame

### 1.2.1.

At the level of the lower bracket as shown in Figure 2, the net section modulus of the frame and bracket, or integral bracket, with associated shell plating, is not to be taken less than twice the required net section modulus $Z$, in cm$^3$,for the frame mid-span area obtained from [1.1.1].

### 1.2.2.

The net thickness $t_{LB}$, in mm, of the lower bracket is not to be taken less than:

$$t_{LB} = t_w + 1.5$$

where $t_w$ is the net thickness of the side frame web, in mm.

### 1.2.3.

The net thickness $t_{LB}$ of the lower bracket is to comply with the following formula:

$(h_{LB}/t_{LB}) \leq 87\sqrt{k}$ for symmetrically flanged frames

$(h_{LB}/t_{LB}) \leq 73\sqrt{k}$ for asymmetrically flanged frames

The web depth $h_{LB}$ of lower bracket is to be measured from the intersection between the hopper tank sloping plating and the side shell plate, perpendicularly to the face plate of the lower bracket as shown in Figure 3.

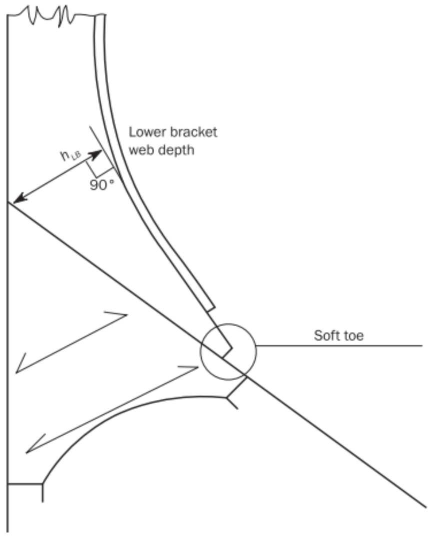



Figure 3 Example of support structure for lower end

For the three side frames located immediately abaft the collision bulkhead, where the frames are strengthened in accordance with [1.1.2] and the offered $t_{LB}$ is greater than $1.73\ t_w$, the $t_{LB}$ applied in [1.2.3] may be taken as $t'_{LB}$ given by:

$t'_{LB} = (t_{LB}^2 t_w)^{1/3}$

where $t_w$ is the net thickness of the side frame web, in mm, corresponding to $A_{shr}$ determined in accordance to [1.1.1].

## 1.3. Upper bracket of side frame

### 1.3.1.

At the level of the upper bracket as shown in Figure 2, the net section modulus of the frame and bracket, or integral bracket, with associated shell plating, is not to be taken less than twice the net section modulus $Z$ required for the frame mid-span area obtained from [1.1.1].

## 1.4. Provided support at upper and lower connections of side frames

### 1.4.1. Net section modulus

The net section modulus of the:

• Side shell and hopper tank longitudinals supporting the lower connecting brackets.

• Side shell and topside tank longitudinals supporting the upper connecting brackets.

is to comply with the following formula:

$$\sum_n Z_{pli} d_i \geq \alpha_T \frac{P\ell_{SF}^2 \ell_1^2}{16R_{eH}}$$

Where:

$n$ : Number of the longitudinal stiffeners on the side shell and hopper/topside tank supporting the lower/upper end connecting bracket of the side frame, as applicable.

$Z_{pli}$ : Net plastic section modulus, in $cm^3$, of the i-th longitudinal stiffener on the side shell or hopper/topside tank supporting the lower/upper end connecting bracket of the side frame, as applicable.

$d_i$ : Distance, in $m$, of the above i-th longitudinal stiffener from the intersection point of the side shell and hopper/topside tank.

$\ell_1$ : Spacing, in $m$, of transverse supporting webs in hopper/topside tank, as applicable.

$R_{eH}$ : Lowest value of specified yield stress, in $N/mm^2$, among the materials of the longitudinal stiffeners of side shell and hopper/topside tanks that support the lower/upper end connecting bracket of the side frame.

$\alpha_T$ : Coefficient taken as:

| | |
|---|---|
| $\alpha_T = 150$ | for the longitudinal stiffeners supporting the lower connecting brackets. |
| $\alpha_T = 75$ | for the longitudinal stiffeners supporting the upper connecting brackets. |

### 1.4.2. Net connection area of brackets

The net connection area, of the lower or upper connecting bracket to the supporting longitudinal stiffener is to comply with the following formula:

$$\sum_i A_i d_i R_{eH,bkt-i} \geq 0.02\alpha_T P s \ell_{SF}^2 10^{-3}$$

Where :

$A_i$ : The offered net connection area of the bracket connecting with the i-th longitudinal stiffener, in $cm^2$.

$d_i$ , $\alpha_T$ : As defined in [1.4.1].

$R_{eH,bkt-i}$ : The specified minimum yield stress of the bracket connecting with the i-th longitudinal stiffener, in $N/mm^2$.

$s$ : The space of the side frame, in mm.

# Section 6 – Supports of Independent Cargo Tanks

## 1. Supports of independent cargo tanks

### 1.1. Scantling requirements

#### 1.1.1. General

Strength of wood or resin of supports should be checked in view of compressive strength and shear strength.

#### 1.1.2. Compressive strength

The compressive stress to comply with the following criteria for wood or resin of supports of independent cargo tanks.

$\sigma_{scantling} < \sigma_{support}$

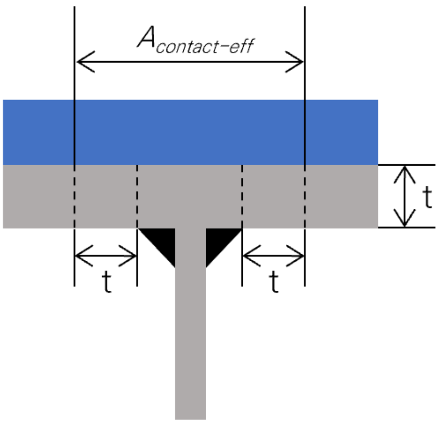
Where:

$\sigma_{scantling}$ : $F_{max-reaction}/A_{contact-eff}$

$\sigma_{support}$ : $R_{support}/C_{a-support}$

$F_{max-reaction}$ : Maximum reaction force from cargo hold analysis, in N.

$A_{contact-eff}$ : Effective contact area, in mm$^2$.




$R_{support}$ : Minimum compressive strength of wood or resin of supports of independent cargo tanks, in N/mm$^2$.

$C_{a-support}$ : 3.0, safety factor for wood or resin of supports of independent cargo tanks.

#### 1.1.3. Shear strength

The shear stress to comply with the following criteria for wood or resin of supports of independent cargo tanks.

$\tau_{scantling} < \tau_{support}$

Where:

$\tau_{scantling}$ : $F_{friction}/A_{shear-support}$

$\tau_{support}$ : $R_{shear-support}/C_{a-support}$

$F_{friction}$ : Friction force at support, in N.

$$F_{friction} = \mu F_{max-reaction}$$

$\mu$ : Friction coefficient.

$A_{shear-support}$ : Shear area of wood or resin of supports of independent cargo tanks, in mm$^2$.

$R_{shear-support}$ : Minimum shear strength of wood or resin of supports of independent cargo tanks, in N/mm$^2$.

$C_{a-support}$ : 3.0, safety factor for wood or resin of supports of independent cargo tanks.

### 1.1.4. Dam plate

The shear stress to comply with the following criteria for dam plate.

$\tau_{scantling-dam} < \tau_{eH}$

Where:

$\tau_{scantling-dam}$ : $0.1\ F_{friction}/A_{shear-dam\ plate}$

$A_{shear-dam\ plate}$ : Shear area of dam plate, in mm$^2$.

$\tau_{eH}$ : Allowable shear stress of dam plate, in N/mm$^2$.

# Chapter 5

# Direct Strength Analysis

# Section 1 – Strength Assessment

## 1. General

### 1.1. Application

#### 1.1.1.

This chapter provides design basis and analysis methodology regarding the structural strength verification of the hull structure using finite element analysis under the applied loads. A flow diagram showing the minimum requirement of finite element analysis is shown in Figure 1.

#### 1.1.2.

The finite element analysis consists of three parts:

a) Cargo hold analysis to assess the strength of longitudinal hull girder structural members, primary supporting structural members and bulkheads.

b) Fine mesh analysis to assess detailed stress levels in local structural details.

c) Very fine mesh analysis to assess the fatigue capacity of the structural details according to **Pt 15, Ch 9 of Rules for the Classification of Steel Ships**.

#### 1.1.3.

Strength assessment based on finite element analysis is applicable for the cargo hold region including the transition areas to engine room and fore end structure. The analysis is to verify the following:

a) Stress levels of structural analysis in accordance with Ch 5, Sec 2 and Ch 5, Sec 3 are within the acceptance criteria for yielding.

b) Buckling capability of plates and stiffened panels are within the acceptance criteria for bucking defined in Ch 6.

c) Fatigue capacity of structural details is within the acceptance criteria defined in **Pt 15, Ch 9 of Rules for the Classification of Steel Ships**.

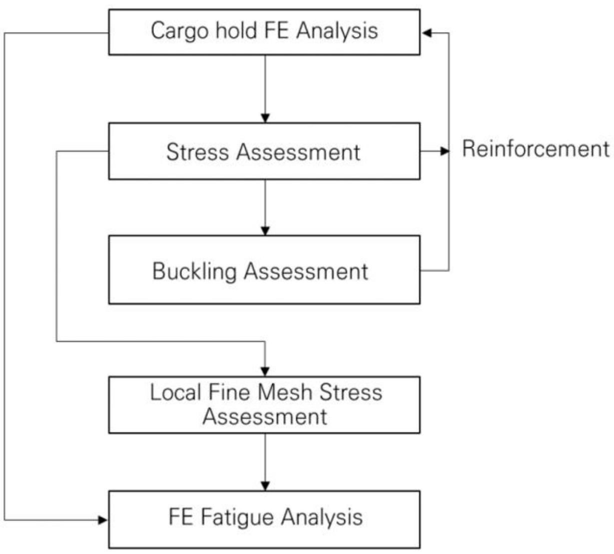



Figure 1 Flow diagram of finite element analysis

### 1.1.4. Scantling application

FE models for cargo hold FE analyses, local fine mesh FE analysis and very fine mesh FE analyses, are to be based on corrosion addition as given in **Pt 15, Ch 3, Sec 2, Table 1 of Rules for the Classification of Steel Ships**.

### 1.1.5. Scantling assessment

The scantling assessment is carried out for each individual cargo hold using the FE load combinations defined in **Sec 2** applicable to the considered cargo hold. The FE analysis results are applicable to the evaluation area as defined in **Sec 2, [5.1]**, of the considered cargo hold.

The individual bulkhead structural elements, inclusive plating, stiffeners and horizontal stringers, are to be assessed considering two cargo hold finite element analyses, i.e. the analysis for the hold forward and the one for the hold aft of the considered transverse bulkhead.

## 2. Finite element types

### 2.1. Used finite element types

### 2.1.1.

The structural assessment is to be based on linear finite element analysis of three dimensional structural models. The general types of finite elements to be used in the finite element analysis are given in **Table 1**.

Table 1 Types of finite element

| Type of finite element | Description |
|---|---|
| Rod (or truss) element | Line element with axial stiffness only and constant cross sectional area along the length of the element. |
| Beam element | Line element with axial, torsional and bi-directional shear and bending stiffness and with constant properties along the length of the element. |
| Shell (or plate) element | Shell element with in-plane stiffness and out-of-plane bending stiffness with constant thickness. |

### 2.1.2.

Two node line elements and four node shell elements are, in general, considered sufficient for the representation of the hull structure. The mesh requirements given in this chapter are based on the assumption that these elements are used in the finite element models. However, higher order elements may also be used.

## 3. Submission of results

### 3.1. Detailed report

### 3.1.1.

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

a) List of structural drawings used including dates and versions.

b) Detailed description of structural modelling including all modelling assumptions and any deviations in geometry and arrangement of structure compared with plans.

c) Plots to demonstrate correct structural modelling and assigned properties.

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

e) Details of applied boundary conditions.

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

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

h) Plots and results that demonstrate the correct behavior of the structural model under the applied loads.

i) Summaries and plots of global and local deflections.

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

k) Plate and stiffened panel buckling analysis and results.

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

m) Reference of the finite element computer program, including its version and date.

## 4. Computer programs

### 4.1. Use of computer programs

#### 4.1.1.

Any finite element computation program complying with **Pt 15, Ch 1, Sec 3 of Rules for the Classification of Steel Ships** may be employed to determine the stress and deflection of the hull structure, provided that the combined effects of bending, shear, axial and torsional deformations are considered.

# Section 2 – Cargo Hold Structural Strength Analysis

## 1. Objective and scope

### 1.1. General

#### 1.1.1.

The cargo hold structural strength analysis is for the assessment of structural strength of longitudinal hull girder structural members, primary supporting members and bulkheads within the cargo hold region including transition areas to engine room and fore end. This section describes the analysis methodology and load application for cargo hold structural strength analysis.

#### 1.1.2.

Cargo hold structural strength analysis is mandatory within the cargo hold region including cofferdam structure i.e. aft bulkhead of the aftmost cargo hold and fore bulkhead of the foremost cargo hold. The evaluation areas are defined in [5.1].

#### 1.1.3.

For the FE structural assessment and load application, at least three cargo holds are to be assessed:

a) Midship cargo hold region

Holds in the midship cargo hold region are defined as holds with their longitudinal centre of gravity position at or forward of 0.3L from AE and at or aft of 0.7L from AE, as defined in Figure 1:

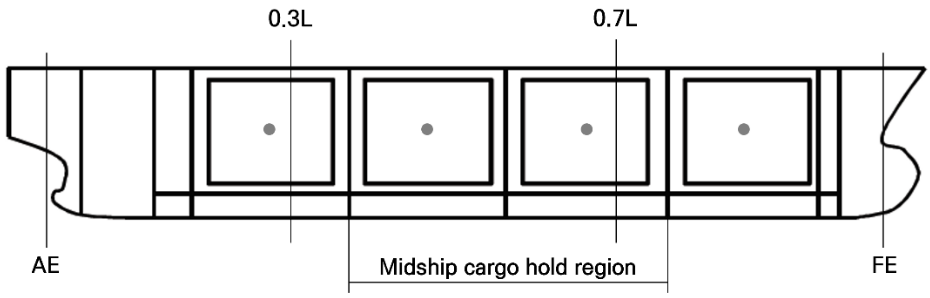



Figure 1 Definition of cargo hold region for FE structural assessment

### 1.2. Cargo hold structural strength analysis procedure

#### 1.2.1. Procedure description

The structural FE analysis is to be performed in accordance with the following:

a) Model: Three cargo hold model with:

• Extent as given in [2.2]

• Finite element types as given in [2.3]

• Structural modelling as defined in [2.4]

b) Boundary conditions as defined in [2.5]

c) FE load combinations as defined in [3]

d) Load application as defined in [4]

e) Evaluation area as defined in [5.1]

f) Strength assessment as defined in [5.2] and [5.3]

#### 1.2.2. Mid-hold definition

For the purpose of the FE analysis, the mid-hold is defined as the middle hold(s) of the three cargo hold length FE model. In case of foremost and aftmost cargo hold assessment, the mid-hold represents the foremost and aftmost cargo hold respectively.

## 2. Structural model

### 2.1. Members to be modelled

#### 2.1.1.

All main longitudinal and transverse structural elements are to be modelled. These include:

• Inner and outer shell,

• Upper deck,

• Double bottom floors and girders,

• Transverse and vertical web frames,

• Cargo tank dome openings,

• Stringers,

• Transverse and longitudinal bulkhead structures,

• Other primary supporting members,

• Other structural members which contribute to hull girder strength.

All plates and stiffeners on the structure, including web stiffeners, are to be modelled. Brackets which contribute to primary supporting member strength and the size of which is not less than the typical mesh size (s-by-s) described in [2.4], are to be modelled.

### 2.2. Extent of model

#### 2.2.1. Longitudinal extent

Generally, the longitudinal extent of the cargo hold FE model is to cover three cargo hold lengths.

#### 2.2.2. Hull form modelling

In general, the finite element model is to represent the geometry of the hull form. In the midship cargo hold region, the finite element model may be prismatic provided the mid-hold has a prismatic shape.

When the hull form is modelled by extrusion, the geometrical properties of the transverse section located at the middle of the considered space are copied along the simplified model. The transverse web frames are to be considered along this extruded part with the same properties as ones in the fore part or in the machinery space.

#### 2.2.3. Transverse extent

Both port and starboard sides of the ship are to be modelled.

#### 2.2.4. Vertical extent

The full depth of the ship is to be modelled including primary supporting members above the upper deck, trunks and forecastle, if any.

The superstructure or deck house in way of the machinery space and the bulwark are not required to be included in the model.

### 2.3. Finite element types

#### 2.3.1.

Shell elements are to be used to represent plates.

#### 2.3.2.

All stiffeners are to be modelled with beam elements having axial, torsional, bi-directional shear and bending stiffness. The eccentricity of the neutral axis is to be modelled.

#### 2.3.3.

Face plates of primary supporting members and brackets are to be modelled using rod or beam elements.

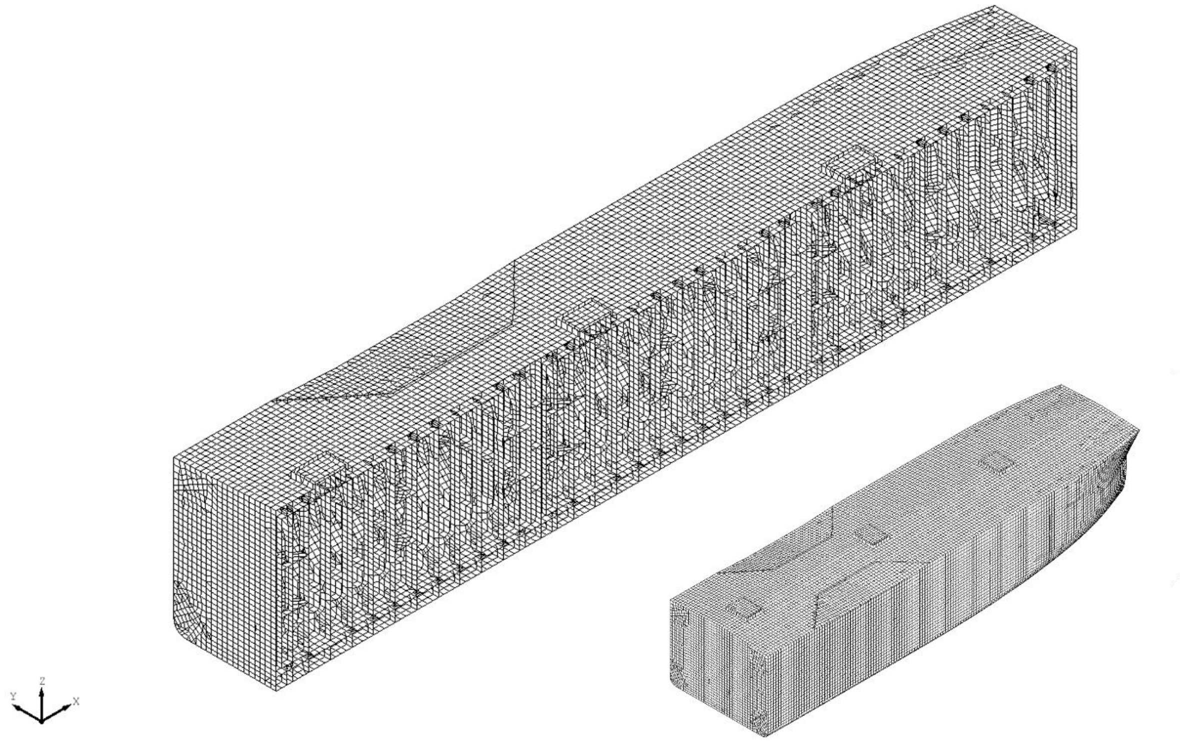


Figure 2 Example of 3 cargo hold model within midship region

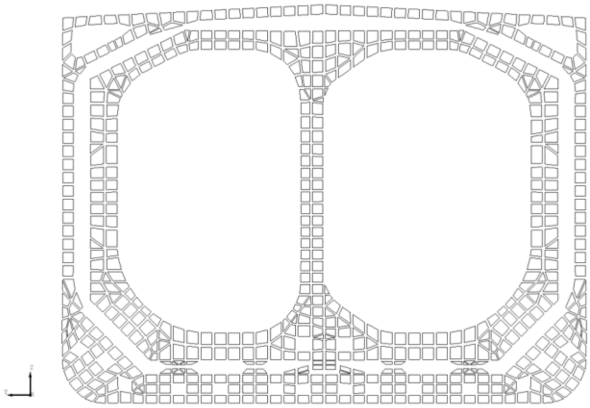


Figure 3 Typical finite element mesh on web frame

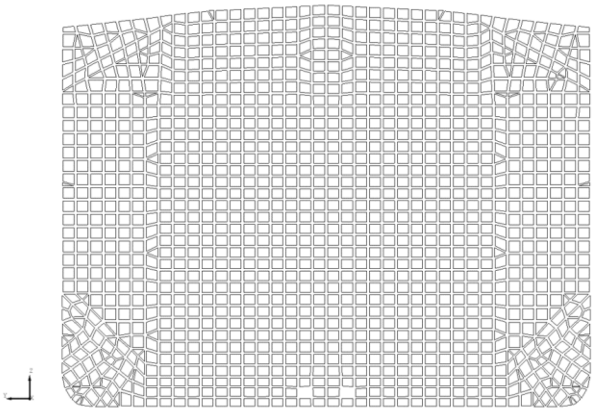


Figure 4 Typical finite element mesh on transverse bulkhead

## 2.4. Structural modelling

### 2.4.1. Supporting structure idealization

a) It is very important to get the force distribution on each support by independent tank. Therefore, all tank supports are to be idealized by shell elements according to the arrangement of tank supports. The spacer between upper and lower seat of the hull and tank supports should be considered using solid elements, gap elements or 1D element such as spring or rod element.

b) If solid elements are used, contact elements should be defined for interface surface. In case of gap elements implementation, the upper and lower surface of tank support seat is to be rigidly linked respectively with 6 DOF constraints. If the gap elements or contact elements are used, analysis results should be obtained using a nonlinear analysis. Figure 6 shows the typical implementation of gap elements with 6 DOF constraints.

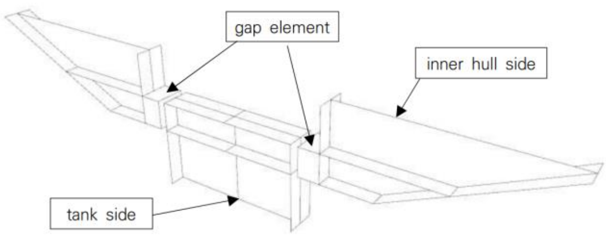



Figure 5 Tank support (Implementation of 1D Gap element with 6 DOF constraints)

c) For the usage of linear 1D element, the spring or axial stiffness is to be calculated based on the actual elastic modulus of the spacer materials. And, an iterative procedure is required to eliminate any spring or rod element sustaining a tensile stress. Spring or rod element may require two or three elements to correctly represent the behaviour of the support.

d) The coefficient of friction between the spacer between upper and lower seat of the tank supports is used according to **Table 2** unless specifically defined in design stage by designer. In case of accidental loading condition i.e. collision and flooded, friction is not considered with a conservative viewpoint.

Table 2 Friction coefficient between wooden spacer and steel plate

| | |
|---|---|
| kinetic friction coefficient | 0.15 |
| static friction coefficient | 0.3 |

2.4.2.

Structural modelling refers to **Part 15** of the **Rules**.

## 2.5. Boundary conditions

### 2.5.1. General

All boundary conditions described in this section are in accordance with the global coordinate system defined in **Pt 15, Ch 4, Sec 1 of Rules for the Classification of Steel Ships**. The boundary conditions given **[2.5.2]** are applicable to cargo hold finite element model analyses in cargo hold region.

### 2.5.2. Boundary Conditions

The rigid links connect the nodes on the longitudinal members at the model ends to an independent point at neutral axis in centreline. The boundary conditions to be applied at the ends of the mid-hold cargo hold FE model are given in **Table 3**. For the case of TA 5 as given in **Table 5** , additional boundary condition as given in **Table 4** is to be applied at the aftward and forward bulkheads of middle hold in the model.

Table 3 Boundary constraints at model ends for mid-hold

| Location | Translation | | | Rotation | | |
|---|---|---|---|---|---|---|
| | $\delta_x$ | $\delta_y$ | $\delta_z$ | $\theta_x$ | $\theta_y$ | $\theta_z$ |
| **Aft End** | | | | | | |
| Indenpendent point | – | Fix | Fix | $M_{T-end}$ | – | – |
| Cross Section | – | Rigid link | Rigid link | Rigid link | – | – |
| **Fore End** | | | | | | |
| Independent point | – | Fix | Fix | Fix | – | – |
| Intersection of centreline and inner bottom | Fix | – | – | – | – | – |
| Cross Section | – | Rigid link | Rigid link | Rigid link | – | – |
| Note 1: [–] means no constraint applied (free).<br>Note 2: See **Figure 6**. | | | | | | |

Table 4 Additional boundary constraints at bulkhead sections for cargo hold model

| Location | Translation | | | Rotation | | |
|---|---|---|---|---|---|---|
| | $\delta_x$ | $\delta_y$ | $\delta_z$ | $\theta_x$ | $\theta_y$ | $\theta_z$ |
| Aft bulkhead in the middle hold | | | | | | |
| Line D, Line B | – | Fix | – | – | – | – |
| fore bulkhead in the middle hold | | | | | | |
| Line D, Line B | – | Fix | – | – | – | – |
| Note 1: [–] means no constraint applied (free).<br>Note 2: See Figure 7. | | | | | | |

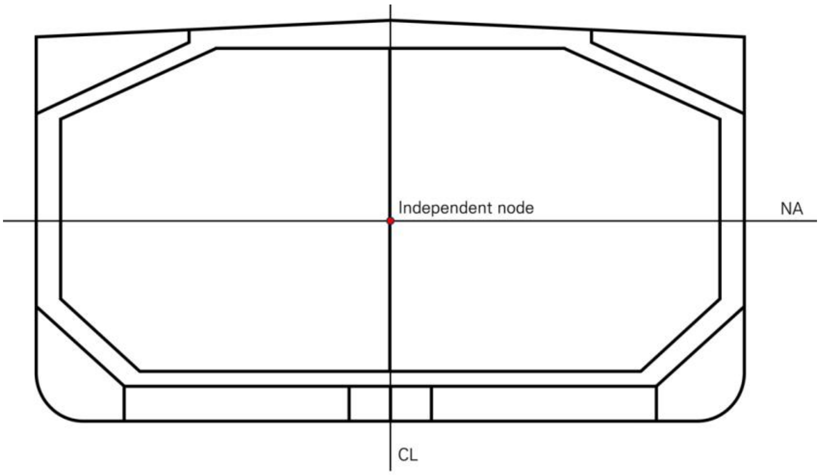



Figure 6 Boundary conditions applied at the model end sections of mid model

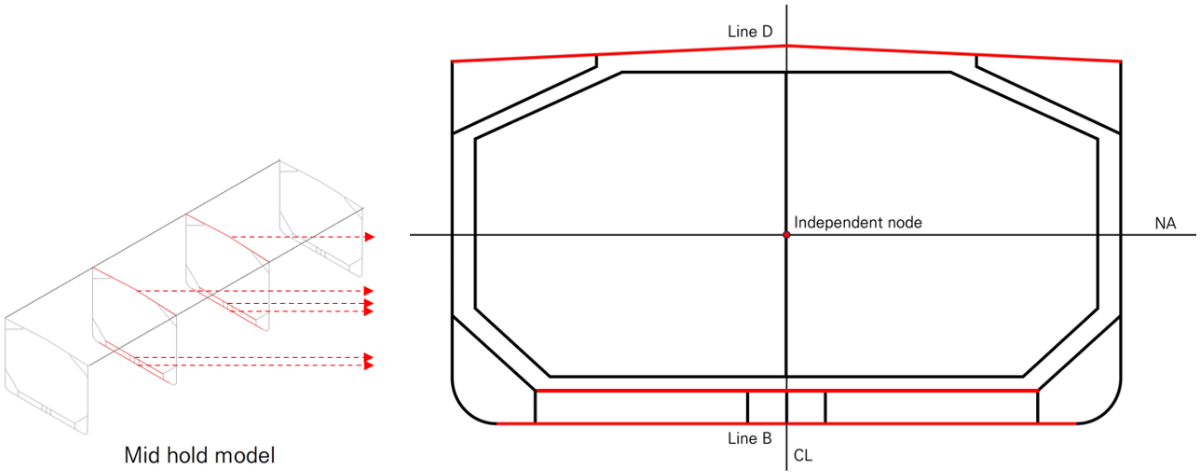



Figure 7 Additional boundary conditions applied at the model

# 3. FE load combinations

## 3.1. Design load combinations

### 3.1.1. FE load combination definition

A FE load combination is defined as a loading pattern, a draught, a value of still water bending and shear force, associated with a given dynamic load case.

### 3.1.2. Loading conditions

Loading conditions to be considered for a strength assessment generally are as follow:

a) Standard loading conditions for yielding and buckling strength assessment are given in [3.1.3].

b) For fatigue assessment, standard designs are given in **Pt 15, Ch 9, Sec 1 of Rules for the Classification of Steel Ships.**.

### 3.1.3. Load combinations

For cargo hold structural strength analysis for midship holds, the design load combinations specified in **Table 5** are to be used as a minimum.

Each design load combination given in **Table 5** consists of a loading pattern and dynamic load cases as given in **Pt 15, Ch 4, Sec 2 of Rules for the Classification of Steel Ships**. Each load combination requires the application of the structural weight, internal and external loads and hull girder loads. For seagoing condition, both static and dynamic load components (S+D) are applied.

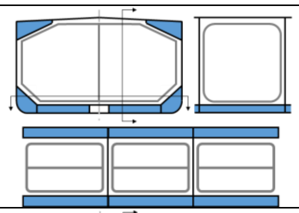
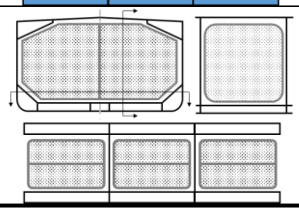
The "maximum shear force load combinations" are marked as "Max SFLC" in the load combination tables of **Table 5**. The "other shear force load combinations" are those which are not the maximum shear force load combinations. They are not marked in the load combination tables of **Table 5**.

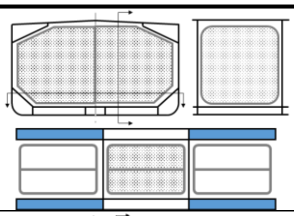
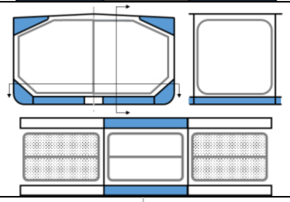
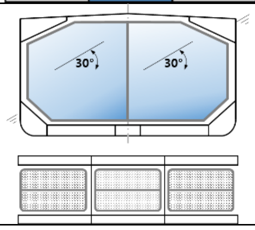
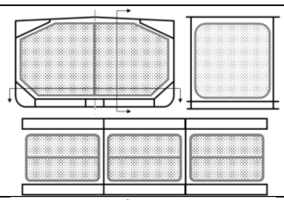
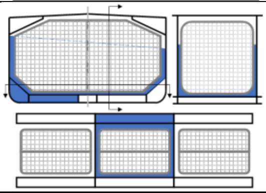
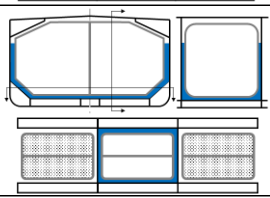
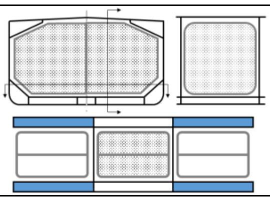
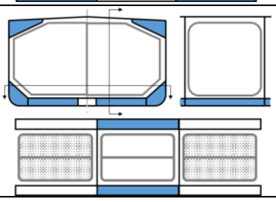
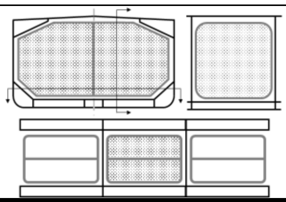
Excessive asymmetric loading shall be avoided, if asymmetric loading is specifically required in the loading manual, these loading conditions are to be documented and also be assessed for compliance.

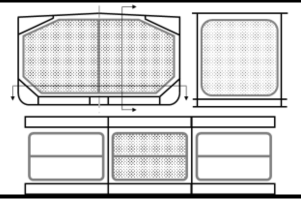
### 3.1.4. Additional loading conditions

Where the loading conditions specified by the designer are not covered by the load combinations given in [3.1.3], these additional loading conditions are to be examined according to the procedure in [4].

**Table 5 Standard loading conditions applicable to cargo hold region**

| No | Loading Pattern | Draught | % of perm. SWBM | % of perm. SWSF | Dynamic load cases | Pressure by IGC (Pt 7, Ch 5, 428) |
|---|---|---|---|---|---|---|
| Seagoing condition | | | | | | |
| TA1 |  | $T_{BAL}$ | 0% Sagging | ≤ 100% | HSM1 | |
| | | | 100% Hogging | ≤ 100% | HSM2, BSR-2P | |
| TA2 |  | $T_{SC}$ | 100% Sagging | ≤ 100% | HSM1, BSR-1P, OST-1P | |
| | | | 0% Hogging | ≤ 100% | HSM2, BSP-1P, BSR-2P | |

| | | | | | | |
|---|---|---|---|---|---|---|
| TA3 |  | $0.75T_{SC}$ | 100% Sagging | 100% Max SFLC | HSM1 | |
| | | | 75% Hogging | ≤ 100% | HSM2 | |
| TA4 |  | $0.9T_{SC}$ | 0% Sagging | ≤ 100% | HSM1 | |
| | | | 100% Hogging | 100% Max SFLC | HSM2, FSM2 | |
| | | | | ≤ 100% | BSR-1P, BSR-2P | |
| TA5 |  | $T_{SC}$ | ≤ 100% | ≤ 100% | N/A | |
| Accidental condition | | | | | | |
| TA6 |  | $T_{SC}$ | ≤ 100% | ≤ 100% | N/A | 0.5g |
| | | | | | | 0.25g |
| TA7 |  | $T_{DAM}$ | ≤ 100% | ≤ 100% | N/A | |
| TA8 |  | $T_{SC}$ | ≤ 100% | ≤ 100% | N/A | |
| Harbour condition | | | | | | |
| TA9 |  | $0.75T_{SC}$ | 100% Sagging | | N/A | |
| TA10 |  | $0.9T_{SC}$ | 100% Hogging | | N/A | |
| Additional loading conditions for tank supports | | | | | | |
| TA12 |  | $0.75T_{SC}$ | 75% Hogging | ≤ 100% | HSA2 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| TA13 |  | $0.65T_{SC}$ | ≤ 100% | ≤ 100% | BSR-1P, BSR-2P<br>BSR-1S, BSR-2S | |

## 4. Load application

Load application refers to **Part 15 of Rules for the Classification of Steel Ships**.

## 5. Analysis criteria

### 5.1. General

#### 5.1.1. Evaluation areas

Verification of results against the acceptance criteria is to be carried out within the longitudinal extent of the mid-hold, as shown in **Figure 8**. The longitudinal extent is from the aft bulkhead of mid-hold to the forward bulkhead of mid-hold.

In cases of TA5 of **Table 5** with additional boundary condition as defined in Table 4, the hull envelope including outer bulkheads, is to be excluded.

And in case of TA12 and TA13 in **Table 5**, only the tank supports are evaluated.

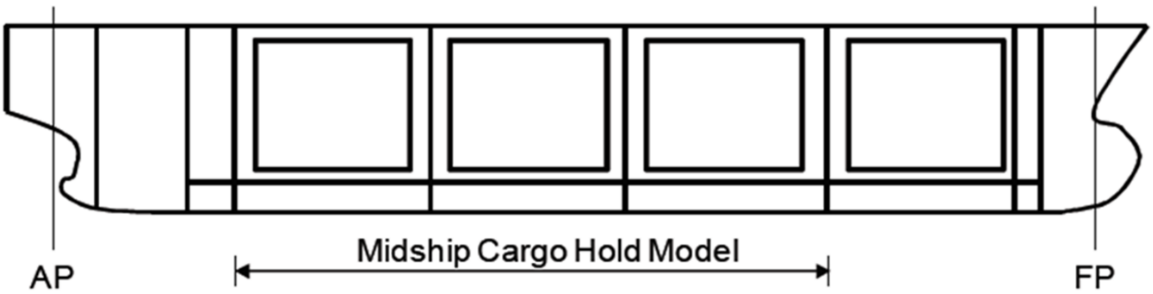



Figure 8 Longitudinal extent of evaluation area

#### 5.1.2. Structural members

The following structural elements within the evaluation area are to be verified with the criteria given in **[5.2]** and **[5.3]**:

• All hull girder longitudinal structural members within Mid-hold including adjacent cofferdams and one web frame spacing more in forward and aftward direction from the cofferdams.

• All primary supporting structural members and bulkheads within the mid-hold.

• All structural members being part of the transverse bulkheads.

## 5.2. Yield strength assessment

### 5.2.1. Von mises stress

For all plates of the structural members defined in [5.1.2], the von Mises stress, $\sigma_{vm}$, in N/mm$^2$, is to be calculated based on the membrane normal and shear stresses of the shell element. The stresses are to be evaluated at the element centroid of the mid-plane (layer), as follows:

$$\sigma_{vm} = \sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

where:

$\sigma_x$, $\sigma_y$ : Element normal membrane stresses, in N/mm$^2$.

$\tau_{xy}$ : Element shear stress, in N/mm$^2$.

### 5.2.2. Axial stress in beams and rod elements

For beams and rod elements, the axial stress, $\sigma_{axial}$, in $N/mm^2$, is to be calculated based on axial force alone. The axial stress is to be evaluated at the middle of element length.

### 5.2.3. Coarse mesh permissible yield utilisation factors

The coarse mesh permissible yield utilisation factors, $\lambda_{yperm}$, given in **Table 6**, are based on the mesh sizes and element types described in [2.3] to [2.4].

The yield utilisation factor resulting from element stresses of each structural component are not to exceed the permissible values as given in **Table 6**.

Table 6 Coarse mesh permissible yield utilisation factor

| Structural component | Coarse mesh permissible yield utilisation factor, $\lambda_{yperm}$ |
|---|---|
| Plating of all longitudinal hull girder structural members, primary supporting structural members and bulkheads.<br>Face plate of primary supporting members modelled using shell or rod elements. | 1.0 (load combination S+D) |
| | 0.8 (load combination S) |
| | 1.0 (load combination A) |

### 5.2.4. Yield criteria

a) Hull

The structural elements given in [5.1.2] are to comply with the following criteria:

$$\lambda_y \leq \lambda_{yperm}$$

Where :

$\lambda_y$ : Yield utilization factor.

$\lambda_y = \frac{\sigma_{vm}}{R_y}$ for shell element in general.

$\lambda_y = \frac{\sigma_{vm}}{R_{eH}}$ for accidental condition or the loading condition with AC-A.

$\lambda_y = \frac{|\sigma_{axial}|}{R_y}$ for rod or beam elements in general.

$\lambda_y = \frac{|\sigma_{axial}|}{R_{eH}}$ for accidental condition or the loading condition with AC-A.

$\sigma_{vm}$ : Von Mises stress, in N/mm$^2$.

$\sigma_{axial}$ : Axial stress in rod or beam element, in N/mm$^2$.

$\lambda_{yperm}$ : Coarse mesh permissible yield utilization factors defined in **Table 6**.

The yield check criteria is to be based on axial stress for the flange of primary supporting members.

Where the von Mises stress of the elements in the cargo hold FE model in way of the area under investigation by fine mesh exceeds the yield criteria, average von Mises stress, obtained from the fine mesh analysis, calculated over an area equivalent to the mesh size of the cargo hold finite element model is to satisfy the yield criteria above.

In way of cut-outs, yield utilisation factor is to be obtained with shear stress correction, as given in **[5.2.6]**.

b) Cargo tanks and supports

The structural elements given in **[5.1.2]** are to comply with the following criteria:

$$\lambda_y \leq \lambda_{yperm}$$

Where :

$\lambda_y$ : Yield utilization factor.

$$\lambda_y = \frac{\sigma_{vm}}{F_{tank}}$$

$$F_{tank} = \gamma_f \frac{R_{eH}}{\gamma_s \cdot \gamma_m}$$

$$\gamma_s = Max(0.76 \cdot \frac{D}{\kappa}, 1.0)$$

$$\kappa = \frac{R_m}{R_{eH}} \cdot \frac{D}{C}$$

$\gamma_f$ : Load Factor, 1.0 for typical Type A tanks,1.05 for a novel design

$\gamma_m$ : Material Factor, 1.02 for material with 390 MPa minimum specific yielding strength above,1.0 for other materials

Table 7 C, D Factors

| | AC-S | AC-SD | AC-A |
|---|---|---|---|
| C | 2.4 | 2.4 | 2.0 |
| D | 1.2 | 1.2 | 1.0 |

### 5.2.5. Shear stress correction for cut-out

Except as indicated in **[5.2.6]**, the element shear stress in way of cut-outs in webs is to be corrected for loss in shear area in accordance with the following formula. The corrected element shear stress is to be used to calculate the von Mises stress of the element for verification against the yield criteria.

$$\tau_{cor} = \frac{h\, t_{mod}}{A_{shr}} \tau_{elem}$$

where :

$\tau_{cor}$ : Corrected element shear stress, in N/mm$^2$.

$h$ : Height of web of girder, in mm, in way of opening. Where the geometry of the opening is modelled, $h$ is to be taken as the height of web of the girder deducting the height of the modelled opening.

$t_{mod}$ : Modelled web thickness, in mm, in way of opening.

$A_{shr}$ : Effective shear area of web, in mm$^2$, taken as the web area deducting the area lost of all openings, including slots for stiffeners, calculated in accordance with **Pt 15, Ch 3, Sec 7, [1.4.8] of Rules for the Classification of Steel Ships**.

$\tau_{elem}$ : Element shear stress, in N/mm$^2$, before correction.

### 5.2.6. Exceptions for shear stress correction for openings

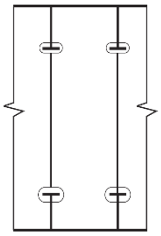
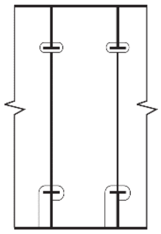
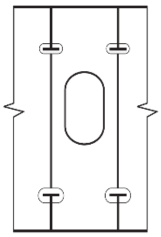
Correction of element shear stress due to presence of cut-outs is not required for cases given in Table 8 provided $\lambda_y/C_r$ complies with the criteria given in [5.2.4].

## 5.3. Buckling strength assessment

### 5.3.1. Allowable buckling utilisation factor

The allowable buckling utilisation factor is defined in Table 9.

Table 8 Exceptions for shear stress correction

| Identification | Figure | Difference between modelled shear area and the effective shear area in % of the modelled shear area $\frac{A_{FEM-n50} - A_{shr-n50}}{A_{FEM-n50}} \cdot 100\%$ | Reduction factor for yield criteria, $C_r$ |
|---|---|---|---|
| Upper and lower slots for local support stiffeners fitted with lugs or collar plates |  | 〈 15% | 0.85 |
| Upper or lower slots for local support stiffeners fitted with lugs or collar plates |  | 〈 20% | 0.80 |
| In way of opening; upper and lower slots for local support stiffeners fitted with collar plates |  | 〈 40% | 0.60 |

$A_{shr-n50}$ : Effective net shear area of web, in $mm^2$, taken as the web area deducting the area lost of all openings, including slots for stiffeners, calculated in accordance with Pt 15, Ch 3, Sec 7, [1.4.8].

Table 9 Allowable buckling utilisation factor

| Structural component | $\eta_{all}$, Allowable buckling utilisation factor |
|---|---|
| Plates and stiffener<br>Stiffened and unstiffened panels<br>Web plate in ways of openings | 1.00 for load combination : S+D<br>0.80 for load combination : S<br>1.00 for load combination : A, T |

| | |
|---|---|
| Cargo tanks and supports | 0.95 for load combination : S+D<br>0.76 for load combination : S<br>1.00 for load combination : A, T |
| Pillars | 0.75 for load combination : S+D<br>0.65 for load combination : S<br>0.75 for load combination : A, T |

# Section 3 – Local Structural Strength Analysis

## 1. Local areas to be assessed by fine mesh analysis

### 1.1. List of mandatory structural details

#### 1.1.1. List of structural details

In the midship cargo hold region, the following structural details are to be assessed:

- Plating and stiffeners of hull and cargo tank structures
- Main supporting members of hull and cargo tank structures, and
- Cargo tank supports and chocks as well as associated seatings in hull and cargo tank structures

The primary concern for the ship structural system is the strength adequacy against external sea, internal liquid pressures, hull girder load effects and other service loads.

It is generally expected that hull girder load effects such as vertical and horizontal bending moments within $0.4L$ amidships are higher than those beyond $0.4L$ amidships. On the other hand, local dynamic loads experienced by hull and cargo tank structures beyond $0.4L$ amidships are more severe than those within $0.4L$ amidships. Furthermore, the fore and after most cargo tanks are generally adjusted to the finer hull geometry beyond $0.4L$ amidships. Therefore, hull and cargo tank structures beyond $0.4L$ amidships are also to be evaluated.

## 2. Structural modelling

### 2.1. General

#### 2.1.1.

Evaluation of detailed stresses requires the use of refined finite element mesh in way of areas of high stress. This fine mesh analysis can be carried out by fine mesh zones incorporated into the cargo hold model.
Alternatively, separate local FE model with fine mesh zones in conjunction with the boundary conditions obtained from the cargo hold model may be used.

#### 2.1.2. Standard local areas

The list of standard local areas selected for fine mesh finite element analysis is to be confirmed by this Society.

a) Hull Structure
   - Dome opening

b) Seatings for Cargo Tank Supports and Chocks
   - Each type of vertical supports
   - Each type of anti-roll chocks
   - Each type of anti-pitch chocks
   - Each type of anti-flotation chocks

When a relatively flexible structural member is connected to a very stiff main supporting member, the connection bracket is to be evaluated using a fine mesh finite element model. Additional critical areas may be selected for novel structural arrangements and connection details.

### 2.2. Extent of model

#### 2.2.1.

If a separate local fine mesh model is used, its extent is to be such that the calculated stresses at the areas of interest are not significantly affected by the imposed boundary conditions. The boundary of the fine mesh model is to coincide with primary supporting members in the cargo hold model, such as web frame, girders, stringers and floors.

## 2.3. Mesh size

### 2.3.1.

The mesh size in the fine mesh zones is not to be greater than 50 $\times$ 50 mm.

### 2.3.2.

The extent of the fine mesh zone is not to be less than 10 elements in all directions from the area under investigation. A smooth transition of mesh density from fine mesh zone to the boundary of the fine mesh model is to be maintained.

## 2.4. Elements

### 2.4.1.

All plating within the fine mesh zone is to be represented by shell elements. The aspect ratio of elements within the fine mesh zone is to be kept as close to 1 as possible. Variation of mesh density within the fine mesh zone and the use of triangular elements are to be avoided. In all cases, the elements within the fine mesh model are to have an aspect ratio not exceeding 3. Distorted elements, with element corner angles of less than 45° or greater than 135°, are to be avoided. Stiffeners inside the fine mesh zone are to be modelled using shell elements. Stiffeners outside the fine mesh zones may be modelled using beam elements.

### 2.4.2.

Where fine mesh analysis is required for main bracket end connections, the fine mesh zone is to be extended at least 10 elements in all directions from the area subject to assessment.

### 2.4.3.

Where fine mesh analysis is required for an opening, it is not recommended to model an opening by deleting elements or having reduced plate thickness as the stresses obtained from such meshing arrangements tend to be unrealistic. If openings are not modeled, the finite element stresses are to be adjusted during post processing for the subsequent strength evaluation to account for reduced effective shear areas.

### 2.4.4.

One acceptable meshing arrangement for a bracket toe for calculating the field or local stress. It is generally not recommended to have the rod or bar element at the tip of the bracket toe directly connected to the attached plating.

### 2.4.5.

Materials such as plywood, resin and adhesive are normally fitted to the contacting surfaces of supports or chocks for the purpose of leveling or alignment. The strength of these materials under compressive or frictional contact forces is to be verified.

### 2.4.6.

The seatings for supports and chocks are to be verified using fine mesh finite element models. Among the supports (or chocks) of the same configuration, a fine mesh finite element model is to be constructed for the one that is subject to the largest contact force.

### 2.4.7.

For each critical structural area, the fine mesh finite element model is to be sufficiently extended to relatively stiff main structural members where the boundary displacements can be properly defined from the global finite element model. Consideration is to be given to the boundary effects on stress distribution in way of the critical structural area.

## 2.5. Fine mesh model of supports

### 2.5.1. Modelling of vertical supports

For each type of vertical supports, two separate fine mesh finite element models are to be analyzed, representing the seatings fitted to the hull and cargo tank structures, respectively.
For the seatings fitted to the hull structure, the fine mesh model is to extend, in the longitudinal direction, forward and aft of the vertical support by one floor spacing. In the transverse direction, the model is to terminate at either side girders or other main support members. In the vertical direction, the full depth of the bottom structure including the seatings is to be modeled.
For the seatings fitted to the cargo tank structure, the fine mesh model is to extend, in the longitudinal and transverse directions, in the same way as described above. Vertically, the model is to cover from the bottom plating of the cargo tank including the seatings to the adjacent horizontal stringer.

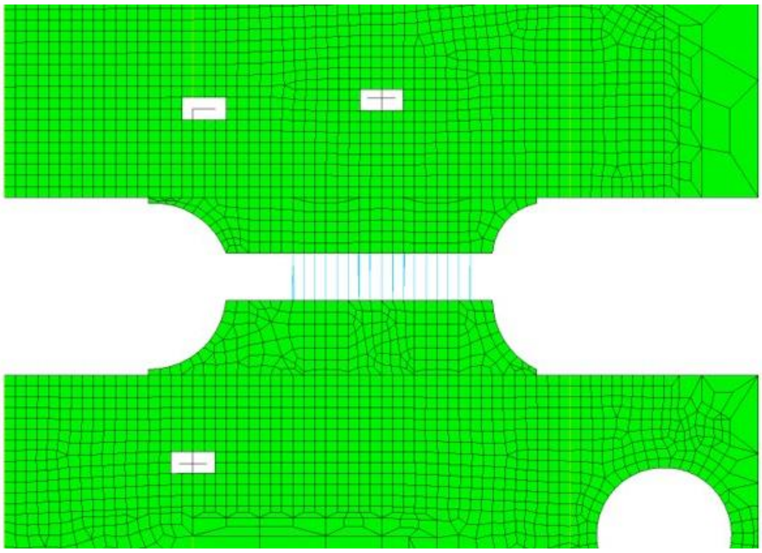


Figure 1 Vertical support

### 2.5.2. Modelling of Anti-Roll Chocks

For each type of anti-roll chocks, two separate fine mesh finite element models are to be analyzed, representing the seatings fitted to the hull and cargo tank structures, respectively.
For the seatings fitted to the hull structure, the fine mesh model is to extend, in the longitudinal direction, forward and aft of the chock by one transverse web frame spacing. In the transverse direction, the model is to terminate at either side girders or other stiff main support members.
For the seatings fitted to the cargo tank structure, the fine mesh model is to extend, in the longitudinal and transverse directions, in the same way as described above. Vertically, the model is to cover from the top plating of the cargo tank including the seatings to the adjacent horizontal stringer.

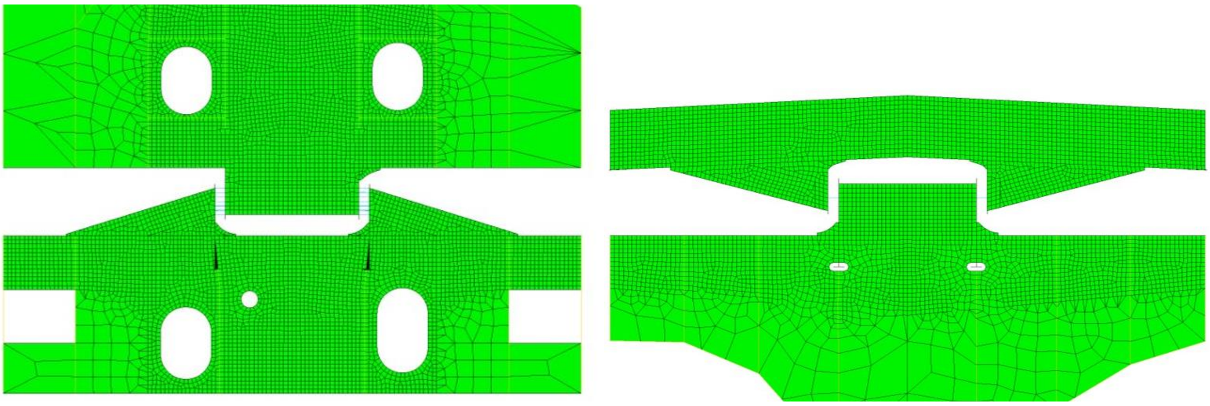


Figure 2 Anti-rolling support

### 2.5.3. Modelling of Anti-Pitch Chocks

For each type of anti-pitch chocks, two separate fine mesh finite element models are to be analyzed, representing the seatings fitted to the hull and cargo tank structures, respectively.
For the seatings fitted to the hull structure, the fine mesh model is to extend, in the longitudinal direction, forward and aft of the chock by one floor spacing. In the transverse direction, the model is to terminate at either side girders or other main support members. In the vertical direction, the full depth of the double bottom is to be modeled. For the seatings fitted to the cargo tank structure, the fine mesh model is to extend, in the longitudinal and transverse directions, in the same way as described above. Vertically, the model is to extend from one main support members to another main support member.

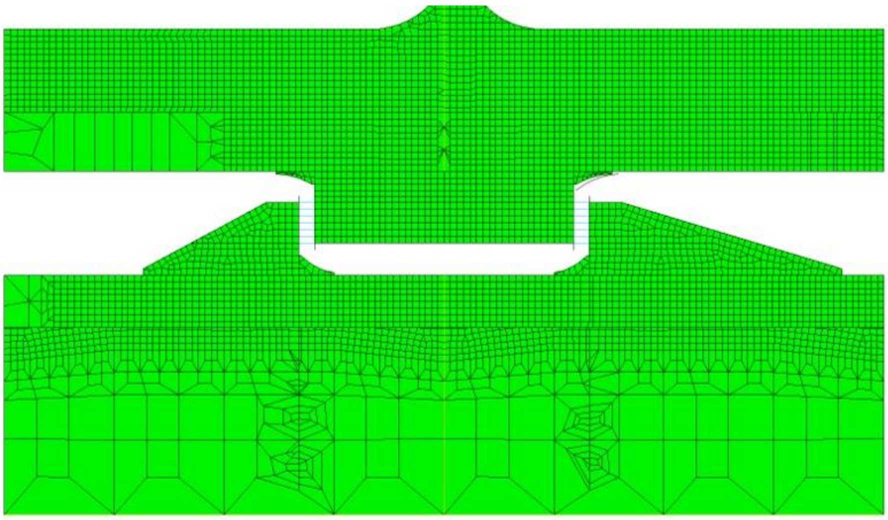


Figure 3 Anti-pitching support

### 2.5.4. Modelling of Anti-Floatation Chocks

For each type of anti-flotation chocks, two separate fine mesh finite element models are to be analyzed. Typically, the seatings are fitted to the cargo tank structure.
For the seatings fitted to the cargo tank structure, the fine mesh model is to extend, in the longitudinal direction, forward and aft of the anti-flotation chock by one web spacing.
For the seatings fitted to the hull structure, the fine mesh model is to extend, in the longitudinal direction, forward and aft of the chock by one web spacing.

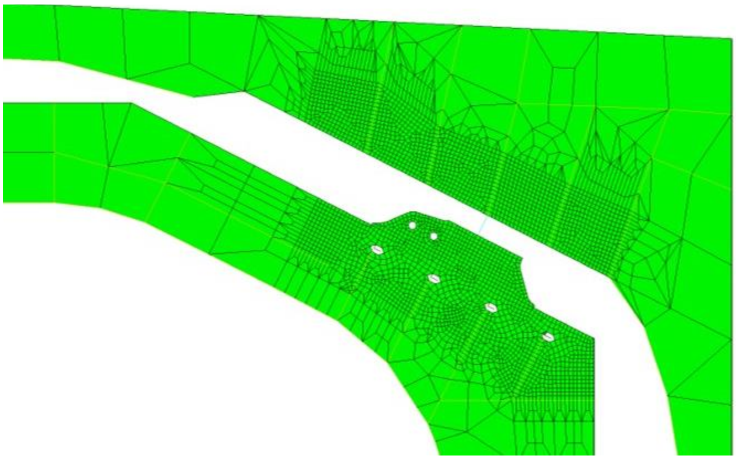


Figure 4 Anti-floating support

## 2.6. FE load combinations

### 2.6.1.

The fine mesh detailed stress analysis is to be carried out for all FE load combinations applied to the corresponding cargo hold analysis.

### 2.6.2. Application of loads and boundary conditions

Where a separate local model is used for the fine mesh detailed stress analysis, the nodal displacements from the cargo tank model are to be applied to the corresponding boundary nodes on the local model as prescribed displacements. Alternatively, equivalent nodal forces from the cargo tank model may be applied to the boundary nodes.

Where there are nodes on the local model boundaries which are not coincident with the nodal points on the cargo tank model, it is acceptable to impose prescribed displacements on these nodes using multi-point constraints. The use of linear multi-point constraint equations connecting two neighbouring coincident nodes is considered sufficient.

All local loads, including any loads applied for hull girder bending moment and/or shear force adjustments, in way of the structure represented by the separate local finite element model are to be applied to the model.

# 3. Analysis criteria

## 3.1. Stress assessment

### 3.1.1.

Stress assessment of the fine mesh analysis is to be carried out for the FE load combinations specified in Ch 5, Sec 2.

### 3.1.2. Reference stress

Reference stress is von Mises stress, $\sigma_{vm}$, which is to be calculated based on the membrane normal and shear stresses of the shell element evaluated at the element centroid. The stresses are to be evaluated at the mid plane of the element.

### 3.1.3. Permissible stress

The maximum permissible stresses are based on the mesh size of 50 × 50 mm as specified in [2].

Where a smaller mesh size is used, an area weighted von Mises stress calculated over an area equal to the specified mesh size may be used to compare with the permissible stresses. The averaging is to be based only on elements with their entire boundary located within the desired area. The average stress is to be calculated based on stresses at element centroid; stress values obtained by interpolation and/or extrapolation are not to be used. Stress averaging is not to be carried across structural discontinuities and abutting structure.

## 3.2. Acceptance criteria

### 3.2.1.

Verification of stress results against the acceptance criteria is to be carried out in accordance with [3.1]. The structural assessment is to demonstrate that the stress complies with the following criteria:

$\lambda_f \le \lambda_{fperm}$

where:

$\lambda_f$ : Fine mesh yield utilisation factor.

$\lambda_f = \frac{\sigma_{vm}}{R_Y}$ for shell elements in general

$\lambda_f = \frac{|\sigma_{axial}|}{R_Y}$ for rod or beam elements in general

$\sigma_{vm}$ : Von Mises stress, in N/mm$^2$.

$\sigma_{axial}$ : Axial stress in rod element, in N/mm$^2$.

$\lambda_{fperm}$ : Permissible fine mesh utilisation factor, taken as:

- Element not adjacent to weld:
- $\lambda_{fperm} = 1.70\ f_f$ for S+D
- $\lambda_{fperm} = 1.36\ f_f$ for S
- Element adjacent to weld:
- $\lambda_{fperm} = 1.50\ f_f$ for S+D
- $\lambda_{fperm} = 1.20\ f_f$ for S

$f_f$ : Fatigue factor, taken as:

- $f_f$=1.0 in general, including the free edge of base material,
- $f_f$=1.2 for details assessed by very fine mesh analysis complying with the fatigue assessment criteria given in **Pt 15, Ch 9, Sec 2 of Rules for the Classification of Steel Ships**.

Note 1: The maximum permissible stresses are based on the mesh size of 50 × 50 mm. Where a smaller mesh size is used, an average von Mises stress calculated in accordance with [3.1] over an area equal to the specified mesh size may be used to compare with the permissible stresses.

Note 2: Average von Mises stress is to be calculated based on weighted average against element areas:

$$\sigma_{vm-av} = \frac{\sum_1^n A_i \sigma_{vm-i}}{\sum_1^n A_i}$$

where:

$\sigma_{vm-av}$ is the average von Mises stress.

Note 3: Stress averaging is not to be carried across structural discontinuities and abutting structure.

# Chapter 6

# Buckling

## Section 1 – General Considerations

# Section 1 – General Considerations

## 1. Introduction

### 1.1. Assumption

#### 1.1.1.

This chapter contains buckling requirements for direct strength analysis. The plate panel of hull structure is to be modelled as stiffened of unstiffened panel. Method A and Method B which are defined as shown in Figure 1, Figure 2 and Figure 3 are to be applied while referring to that of single hull bulk carrier prescribed in Pt 13, Ch 8, Sec 4 of Rules for the Classification of Steel Ships. Buckling assessments are to comply with the principles and requirements of Part 15 of Rules for the Classification of Steel Ships except for the requirements specified in this Guideline.

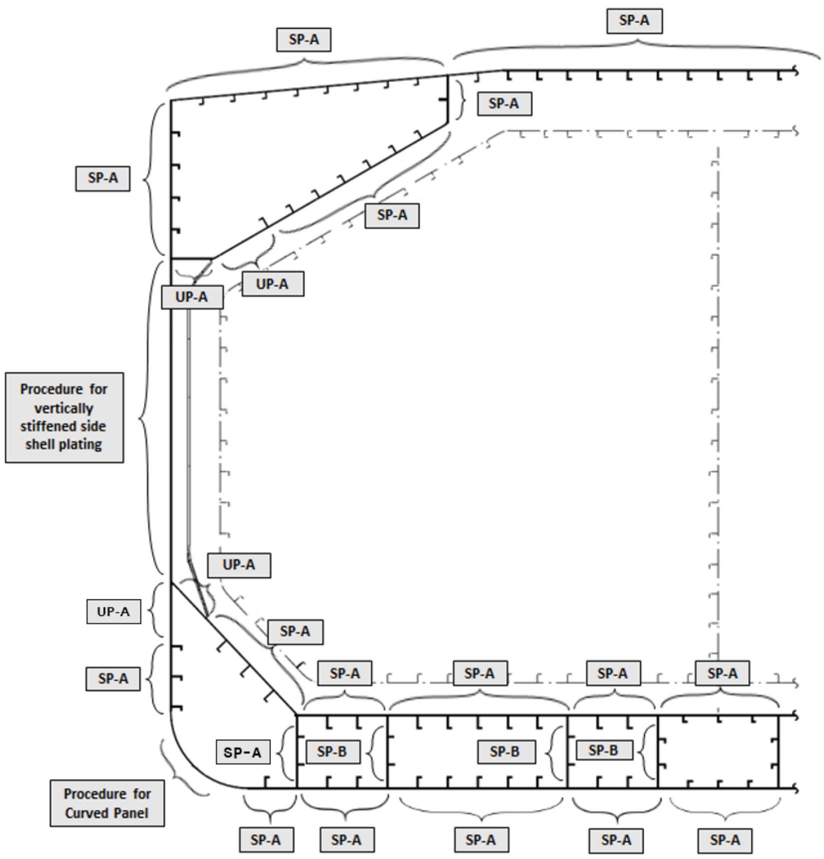



Figure 1 Longitudinal plates in Type A gas carrier

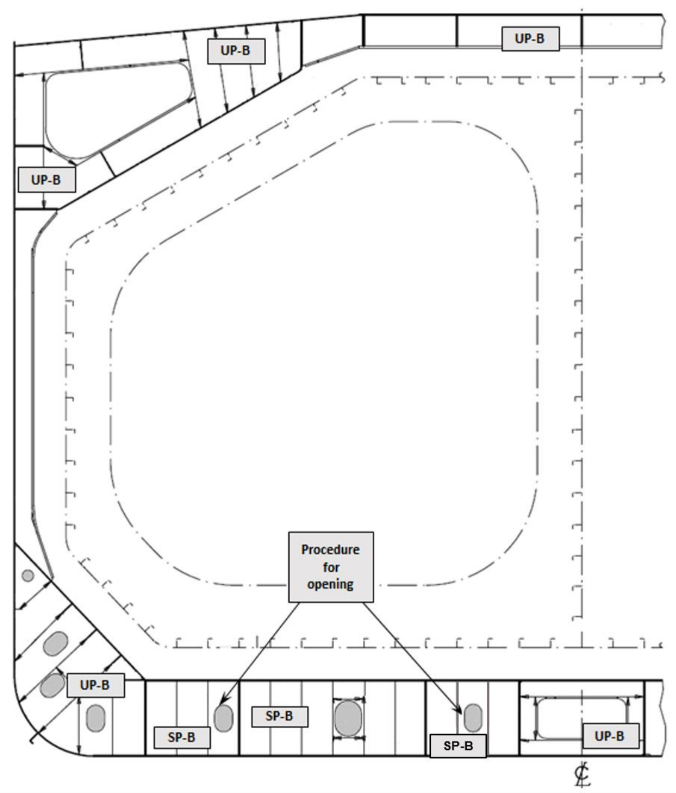



Figure 2 Transverse web frame in Type A gas carrier

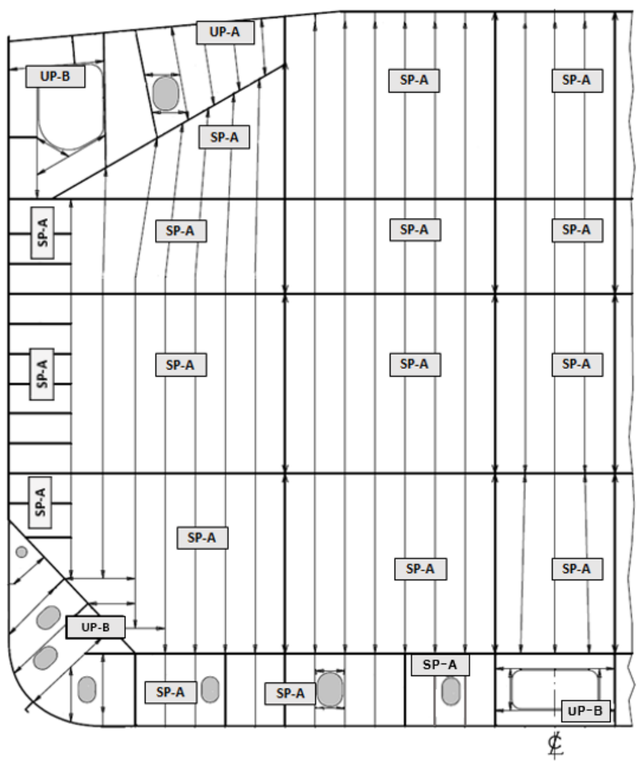



Figure 3 Transverse bulkhead in Type A gas carrier

# Chapter 7

# Fatigue

## Section 1 – General Considerations

# Section 1 – General Considerations

## 1. Introduction

### 1.1. Assumption

#### 1.1.1.

This chapter contains fatigue requirements to evaluate fatigue strength of the ship's structural details considering an operation time in worldwide environment for unrestricted navigation. A more severe trading route may be specified e.g. North Atlantic. Fatigue assessments are to comply with the principles and requirements of **Pt.15, Ch.9 of Rules for the Classification of Steel Ships**.
And when fatigue assessment by finite element stress analysis is performed at the request of the designer, the support structure and independent tank shall be maintained linearly by contact without a slip.