

# RULES FOR CLASSIFICATION

## High speed and light craft

Edition December 2015

### **Part 3 Structures, equipment**

### **Chapter 3 Hull structural design, aluminium**

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## FOREWORD

DNV GL rules for classification contain procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification.

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## CHANGES – CURRENT

This is a new document.

The rules enter into force 1 July 2016.

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## SECTION 1 STRUCTURAL PRINCIPLES

### 1 General

#### 1.1 Applicability

**1.1.1** This chapter is applicable for all craft built in aluminium. It is also applicable to parts built in aluminium on craft built in a different material.

#### 1.2 The scantling reduction

**1.2.1** The scantling reductions for high speed and light craft structures compared with Rules for Classification of Ships are based on:

- a certain stiffener spacing reduction ratio  $s/s_r$   
 $s$  = chosen spacing in m  
 $s_r$  = basic spacing =  $2(100 + L)/1000$  [m] in general
- longitudinal stiffening in bottom and strength deck
- extended longitudinal and local buckling control
- a sea and weather service restriction.

#### 1.3 Aluminium alloys

**1.3.1** The alloy grades are listed in [Sec.2 Table 1](#) to [Sec.2 Table 4](#).

**1.3.2** The various formulae and expressions involving the factor  $f_1$  may be applied when:

$$f_1 = s_f / 240$$

$\sigma_f$  = yield stress and shall not be taken greater than 70% of the ultimate tensile strength.

The material factor  $f_1$  included in the various formulae and expressions is given in [Sec.2 Table 1](#) to [Sec.2 Table 3](#) for the un-welded condition and in [Sec.2 Table 4](#) for the welded condition.

#### 1.4 Documentation

**1.4.1** Documentation shall be submitted as required by [Table 1](#).

**Table 1 Documentation requirements**

<i>Object</i>	<i>Documentation type</i>	<i>Additional description</i>	<i>Info</i>
Structural materials, aluminium	M010 - Material specifications, metals	Including welding consumables	FI
Coating	M040 – Coating specification		FI
Sacrificial anodes	M050 – Cathodic protection specification, calculations and drawings	See also guidance note to <a href="#">[1.3.1]</a>	AP

<i>Object</i>	<i>Documentation type</i>	<i>Additional description</i>	<i>Info</i>
Structural fabrication	H131 – Non-destructive testing (NDT) plan		AP
Vibrations	Z243 – Assessment report	Evaluation of structural response to vibrations caused by impulses from engine, propeller blades and jet units.	FI
Welding	H140 – Welding tables		AP
AP = For approval; FI = For information ACO = As carried out; L = Local handling; R = On request; TA = Covered by type approval; VS = Vessel specific			

For general requirements to documentation, including definition of the info codes, see [SHIP Pt.1 Ch.3 Sec.2](#).  
For a full definition of the documentation types, see [SHIP Pt.1 Ch.3 Sec.3](#).

## 1.5 Certificates

**1.5.1** For products that shall be installed on board, the Builder shall request the Manufacturers to order certification as described in [Table 2](#).

**Table 2 Certification requirements**

<i>Object</i>	<i>Certificate type</i>	<i>Issued by</i>	<i>Certification standard*</i>	<i>Additional description</i>
Structural materials, aluminium	MC	Society		Rolled and extruded wrought aluminium alloys
Materials for special parts	MC	Society		Requirements for material certificates for forgings, castings and other materials for special parts and equipment are stated in connection with the rule requirements for each individual part.
*Unless otherwise specified the certification standard is the rules. PC = Product Certificate, MC = Material certificate, TR = Test report				

For general certification requirements, see [SHIP Pt.1 Ch.3 Sec.4](#).  
For a definition of the certification types, see [RU SHIP Pt.1 Ch.1. Sec.4](#) and [SHIP Pt.1 Ch.3 Sec.5](#).

## 2 Side structure

### 2.1 Stiffeners

**2.1.1** The craft's sides may be longitudinally or vertically stiffened.

**Guidance note:**

It is advised that longitudinal stiffeners are used near bottom and strength deck.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

**2.1.2** The continuity of the longitudinals is to be as required for bottom and deck longitudinals respectively.

## 3 Bottom structures

### 3.1 Longitudinal stiffeners

**3.1.1** Single bottoms as well as double bottoms are normally to be longitudinally stiffened.

**3.1.2** The longitudinals should preferably be continuous through transverse members. If they are to be cut at transverse members, i.e. watertight bulkheads, continuous brackets connecting the ends of the longitudinals are to be fitted or welds are to be dimensioned accordingly.

**3.1.3** Longitudinal stiffeners are to be supported by bulkheads and web frames.

**3.1.4** Longitudinal stiffeners in slamming areas shall have a connection to the frame or bulkhead able to transfer the shear load.

### 3.2 Web frames

**3.2.1** Web frames are to be continuous around the transverse section. Intermediate floors may be used.

**3.2.2** In the engine room plate floors are to be fitted at every frame. In way of thrust bearings additional strengthening is to be provided.

### 3.3 Longitudinal girders

**3.3.1** Web plates of longitudinal girders are to be continuous in way of transverse bulkheads.

**3.3.2** A centre girder is normally to be fitted for docking purposes.

**3.3.3** Manholes or other openings should not be positioned at ends of girders without due consideration being taken of shear loadings.

### 3.4 Engine girders

**3.4.1** Under the main engine, girders extending from the bottom to the top plate of the engine seating are to be fitted.

**3.4.2** Engine holdingdown bolts are to be arranged as near as practicable to floors and longitudinal girders.

**3.4.3** In way of thrust bearing and below pillars additional strengthening is to be provided.

## 3.5 Double bottom, if fitted

**3.5.1** Manholes are to be cut in the inner bottom, floors and longitudinal girders to provide access to all parts of the double bottom. The vertical extension of lightening holes is not to exceed one half of the girder height. Centre of lightening holes to be, as close as practicable, to the neutral axes of elements in question. The edges of the manholes are to be smooth. Manholes in the inner bottom plating are to have reinforcement rings. Manholes are not to be cut in the floors or girders in way of pillars.

**3.5.2** In double bottoms with transverse stiffening, longitudinal girders are to be stiffened at every transverse frame.

**3.5.3** The bottom girders are to be satisfactorily stiffened against buckling.

## 4 Deck structure

### 4.1 Longitudinal stiffeners

**4.1.1** Decks are normally to be longitudinally stiffened.

**4.1.2** Longitudinals, if broken on each side of a bulkhead, are to be connected by aligned brackets on each side of the bulkhead.

**4.1.3** The plate thickness is to be such that the necessary transverse buckling strength is achieved, or transverse buckling stiffeners may have to be fitted intercostally.

### 4.2 Bulwarks

**4.2.1** The thickness of bulwark plates is not to be less than required for side plating in a superstructure in the same position.

**4.2.2** A strong bulb section or similar is to be continuously welded to the upper edge of the bulwark. Bulwark stays are to be in line with transverse beams or local transverse stiffening. The stays are to have sufficient width at deck level. The deck beam is to be continuously welded to the deck in way of the stay. Bulwarks on forecastle decks are to have stays fitted at every frame.

Stays of increased strength are to be fitted at ends of bulwark openings. Openings in bulwarks should not be situated near the ends of superstructures.

**4.2.3** Where bulwarks on exposed decks form wells, ample provision is to be made to freeing the decks for water.

## 5 Flat cross structure

### 5.1 Definition

**5.1.1** *Flat cross structure* is horizontal structure above waterline like bridge connecting structure between twin hulls, etc.

## 5.2 Longitudinal stiffeners

**5.2.1** Flat cross structures are normally to be longitudinally stiffened.

**5.2.2** The longitudinals should preferably be continuous through transverse members. If they are to be cut at transverse members, i.e. watertight bulkheads, continuous brackets connecting the ends of the longitudinals are to be fitted or welds are to be dimensioned accordingly.

**5.2.3** Longitudinal stiffeners are to be supported by bulkheads and web frames.

## 6 Bulkhead structures

### 6.1 Transverse bulkheads

**6.1.1** Number and location of transverse watertight bulkheads are to be in accordance with the requirements given in [Ch.1 Sec.2 \[1.2\]](#).

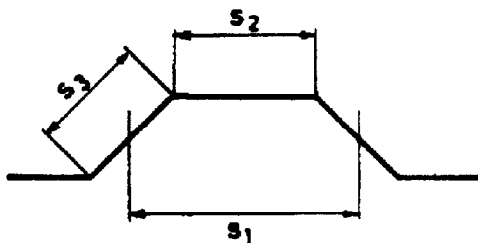
**6.1.2** The stiffening of the upper part of a plane transverse bulkhead is to be such that the necessary transverse buckling strength is achieved.

### 6.2 Corrugated bulkheads

**6.2.1** Longitudinal and transverse bulkheads may be corrugated.

**6.2.2** For corrugated bulkheads the following definition of spacing applies (see [Figure 1](#)):

$s$  =  $s_1$  for section modulus calculations  
 =  $1.05 s_2$  or  $1.05 s_3$  for plate thickness calculations.



**Figure 1 Corrugated bulkhead**

## 7 Superstructures and deckhouses

### 7.1 Definitions

**7.1.1** *Superstructure* is defined as a decked structure on the freeboard deck, extending from side to side of the ship or with the side plating not inboard of the shell plating more than 4% of the breadth (B).

**7.1.2** *Deckhouse* is defined as a decked structure above the strength deck with the side plating being inboard of the shell plating more than 4% of the breadth (B).

*Long deckhouse* - deckhouse having more than 0.2 L of its length within 0.4 L amidships.

*Short deckhouse* - deckhouse not defined as a long deckhouse.

## 7.2 Structural continuity

**7.2.1** In superstructures and deckhouses, the front bulkhead is to be in line with a transverse bulkhead in the hull below or be supported by a combination of deck girders, deck transverses and pillars. The after end bulkhead is also to be effectively supported. As far as practicable, exposed sides and internal longitudinal and transverse bulkheads are to be aligned with primary structure deck elements and are to be in line in the various tiers of accommodation. Where such structural arrangement in line is not possible, there is to be other effective support.

**7.2.2** Sufficient transverse strength is to be provided by means of transverse bulkheads or girder structures.

**7.2.3** At the break of superstructures, which have no set-in from the ship's side, the side plating is to extend beyond the ends of the superstructure, and is to be gradually reduced in height down to the deck or bulwark. The transition is to be smooth and without local discontinuities. A substantial stiffener is to be fitted at the upper edge of plating. The plating is also to be additionally stiffened.

**7.2.4** In long deckhouses, openings in the sides are to have well rounded corners. Horizontal stiffeners are to be fitted at the upper and lower edge of large openings for windows.

Openings for doors in the sides are to be substantially stiffened along the edges. The connection area between deckhouse corners and deck plating is to be increased locally.

**7.2.5** Deck beams under front and aft ends of deckhouses are not to be scalloped for a distance of 0.5 m from each side of the deckhouse corners.

**7.2.6** For deckhouse side stiffeners the scantlings need not be greater than required for tween deck frames with equivalent end connections.

**7.2.7** Casings supporting one or more decks above are to be adequately strengthened.

## 8 Structural design in general

### 8.1 Craft arrangement

**8.1.1** Attention is drawn to the importance of structural continuity in general.

**8.1.2** The craft arrangement is to take into account:

- continuity of longitudinal strength, including horizontal shear area to carry a strength deck along
- transverse bulkheads or strong webs
- web or pillar rings in engine room
- twin hull connections
- access for inspection
- superstructures and deckhouses:
  - direct support
  - transitions
  - deck equipment support
- multi-deck pillars in line, as practicable
- external attachments, inboard connections.

**8.1.3** Structural details in spaces that will be coated are to be designed in such way that a sound layer of coating can be achieved everywhere.

## 8.2 Soft local transitions

**8.2.1** Gradual taper or soft transition is especially important in high speed aluminium vessels, to avoid:

- stress corrosion and fatigue in heavy stressed members
- impact fatigue in impact loaded members.

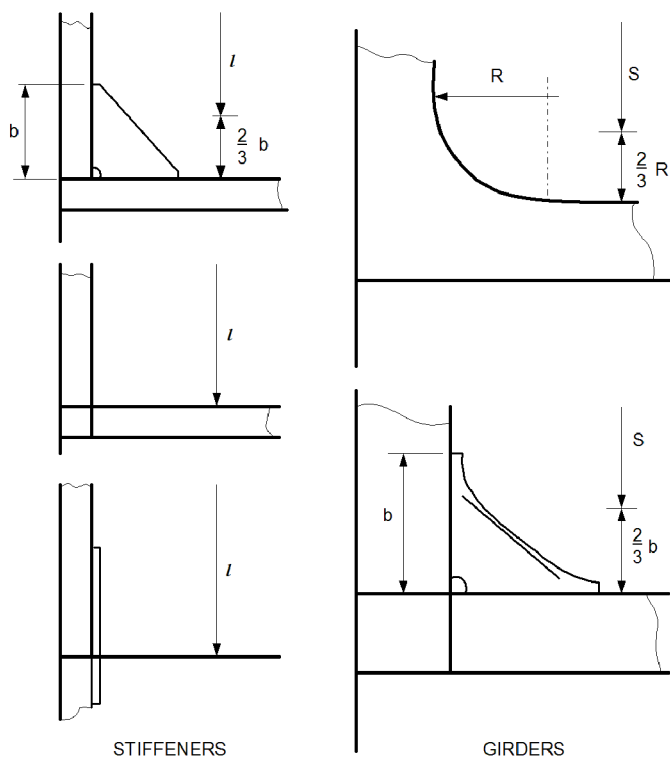
**8.2.2** End brackets, tripping brackets etc. are not to terminate on unsupported plating.

Brackets are to extend to the nearest stiffener, or local plating reinforcement is to be provided at the toe of the bracket.

## 9 Some common local design rules

### 9.1 Definition of span

**9.1.1** The *effective span* of a stiffener ( $l$ ) or girder ( $S$ ) depends on the design of the end connections in relation to adjacent structures. Unless otherwise stated the span points at each end of the member, between which the span is measured, is to be determined as shown on [Figure 2](#). It is assumed that brackets are effectively supported by the adjacent structure. For stiffeners, see also [Figure 2](#) or [Sec.5](#).



**Figure 2 Span points**



## 9.2 Effective girder flange

**9.2.1** For girders with curved face plate, e.g. web frames, the effective area of the flange is given by:

$$A_e = k t_f b_f \text{ (mm}^2\text{)}$$

$b_f$  = total face plate breadth in mm

$k$  = flange efficiency coefficient, see also [Figure 3](#)

$$= k_1 \frac{\sqrt{rt_f}}{b}$$

= 1.0 maximum

$$k_1 = \frac{0.643(\sinh\beta \cosh\beta + \sin\beta \cos\beta)}{\sinh^2\beta + \sin^2\beta}$$

= for symmetrical and unsymmetrical free flange

$$= \frac{0.78(\sinh\beta + \sin\beta)(\cosh\beta - \cos\beta)}{\sinh^2\beta + \sin^2\beta}$$

= for girder flange with two webs

$$= \frac{1.56(\cosh\beta - \cos\beta)}{\sinh\beta + \sin\beta}$$

= for box girder flange with multiple webs

$$\beta = \frac{1.285b}{\sqrt{rt_f}} \text{ (rad)}$$

$b$  = 0.5 ( $b_f - t_w$ ) for symmetrical free flanges

=  $b_f$  for unsymmetrical free flanges

=  $s - t_w$  for box girder flanges

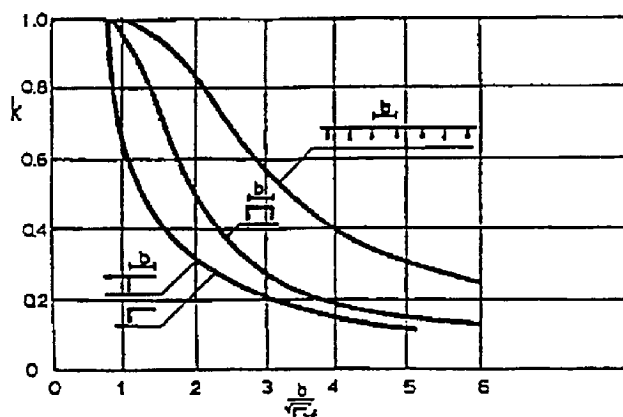
$s$  = spacing of supporting webs for box girder (nun)

$t_f$  = face plate thickness in general (mm)

=  $t_w$  (maximum) for unsymmetrical free flanges

$t_w$  = web plate thickness (mm)

$r$  = radius of curved face plate (mm)



**Figure 3 Effective width of curved face plates for alternative boundary conditions**

**9.2.2** The effective width of curved plate flanges, or effective width of plate at knuckles, is to be specially considered.

### 9.3 Sniped stiffeners

**9.3.1** Stiffeners with sniped ends may be allowed where dynamic loads are small and vibrations considered to be of small importance.

### 9.4 Floating frames

**9.4.1** Floating frames are considered beams supporting extruded panels (plating and stiffeners together).

**9.4.2** Profiles that may be used for floating frames are double flanged profiles (e.g. I or C profiles). Single flanged profiles (e.g. T profiles) are not acceptable.

**9.4.3** Floating frames may be used in Decks, Bulkheads, Side Shell Aft, etc., generally in low stress area and where only static loads are foreseen.

**9.4.4** Floating frames cannot be used in Hull Bottom, Side Fore Body Area, etc., generally in highly stressed areas and / or areas where dynamic loads are foreseen.

**9.4.5** Attached panels cannot be considered participating in strength of floating frames. Section properties of floating frames to be calculated only for bare profile.

**9.4.6** Allowable stresses as stipulated in [Sec.6 \[1.4\]](#) and [Sec.9 \[4.4\]](#) may be increased by 5% after special considerations.

## 10 Support of equipment and outfitting details

### 10.1 Heavy equipment, appendages etc.

**10.1.1** Whether the unit to be supported is covered by classification or not, the forces and moments at points of attachment have to be estimated and followed through hull reinforcements in line, through craft girder and pillar system (taking into account hull stresses already existing) until forces are safely carried to craft's side or bulkheads.

**10.1.2** Doublers should be avoided normal to a tensile force.

### 10.2 Minor outfitting details

**10.2.1** Generally connections of outfitting details to the hull are to be such that stress-concentrations are minimized and welding to high stressed parts are avoided wherever possible.

Connections are to be designed with smooth transitions and proper alignment with the hull structure elements. Terminations are to be supported.

**10.2.2** Connections to topflange of girders and stiffeners are to be avoided if not well smoothened. Preferably supporting of outfittings are to be welded to the stiffener web.

## 11 Structural aspects not covered by rules

### 11.1 Deflections

**11.1.1** Requirements for minimum moment of inertia or maximum deflection under load are limited to structure in way of hatches and doors and some other special cases.

**11.1.2** Deflection problems in general are left to designer's consideration.

### 11.2 Local vibrations

**Guidance note:**

HSC Code 3.4:

*Cyclic loads, including those from vibrations which can occur on the craft should not:*

- a) impair the integrity of structure during the anticipated service life of the craft or the service life agreed with the Administration;
- b) hinder normal functioning of machinery and equipment; and
- c) impair the ability of the crew to carry out its duties.

Upon request such evaluation may be undertaken by the Society.

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## SECTION 2 MATERIALS AND MATERIAL PROTECTION

### 1 General

#### 1.1 Application

**1.1.1** The rules in this chapter apply to wrought aluminium alloys for objects classified or intended for classification with the Society.

#### 1.2 Material certificates

**1.2.1** For class certificate requirement for chemical composition, mechanical properties, heat treatment and repair of defects, see [Pt.2 Ch.2](#).

**1.2.2** Particular attention is to be given to aluminium hull materials specification in [Pt.2 Ch.2 Sec.10](#).

### 2 Structural aluminium alloy

#### 2.1 General

**2.1.1** Aluminium alloy for marine use may be applied in hulls, superstructures, deckhouses, hatch covers and sundry items.

#### 2.2 Aluminium grades

**2.2.1** Aluminium alloys are to have a satisfactory resistance to corrosion in marine environments. Grades for welded structures are to be weldable, applying one of the welding methods approved by the Society.

**2.2.2** For major hull structural components, alloys with temper H116/H321 for rolled products, and alloys with temper T5/T6 for extruded products, are normally to be used. The use of O- or F temper must be agreed with the Society.

**2.2.3** The use of 6000 series aluminium alloys in direct contact with sea water may be restricted depending on application and corrosion protection system. The use of these alloys are to be agreed with the Society.

**2.2.4** In weld zones (HAZ) of rolled or extruded products, the factor  $f_1$  given in [Table 4](#) may in general be used as basis for the scantling requirements.

**2.2.5** Welding consumables are to be chosen according to [Pt.2 Ch.4 Sec.4 Table 7](#). The consumable chosen are to have minimum mechanical properties not less than specified for the parent alloy in the welded condition.

#### 2.3 Chemical composition

**2.3.1** The chemical composition is to satisfy the requirements in [Pt.2 Ch.2 Sec.10 \[1.7\]](#). Other alloys or alloys which do not fully comply with [Pt.2 Ch.2 Sec.10](#), may be accepted by the Society after consideration in each particular case. Special tests and/or other relevant information, e.g. which confirm a satisfactory corrosion resistance and weldability, may be required.

## 2.4 Mechanical properties

**2.4.1** Requirements to mechanical properties for different delivery conditions are given in [Table 1](#) and [Table 2](#) for wrought products, extruded products and rivet bars/-rivets, respectively. Other delivery conditions with related mechanical properties may be accepted by the Society after consideration in each particular case.

**Table 1 Factor  $f_1$  for wrought aluminium alloy sheets, strips and plates,  $t$ : 2 mm  $\leq$   $t$   $\leq$  40 mm**

<i>DNV GL Designation</i>	<i>Temper</i>	$f_1$
VL-5052	H32	0.61
	H34	0.69
VL-5154A	0, H111	0.35
VL-5754	H24	0.69
VL-5454	H32	0.73
	H34	0.79
VL-5086	H116, H32	0.80
	H34	0.88
VL-5083	H116, H321	0.89
VL-5383	H116, H34	0.89
Note: For tempers 0 and H111, the factor $f_1$ is to be taken from <a href="#">Table 4</a> .		

**Table 2 Factor  $f_1$  for extruded aluminium alloy profiles, rods and tubes,  $t$ : 2 mm  $\leq$   $t$   $\leq$  25 mm**

<i>DNV GL Designation</i>	<i>Temper</i>	$f_1$
VL-6060	T5	0.55
VL-6061	T4	0.46
	T5/T6	0.76
VL-6063	T5	0.44
	T6	0.60
VL-6005A	T5/T6	0.76
VL-6082	T4	0.46
	T5/T6	0.90
Note: <a href="#">Table 2</a> only applies when the main loading direction is longitudinal to the extrusion, see also <a href="#">Table 3</a> .		

**Table 3 Factor  $f_1$  for extruded aluminium alloy profiles, rods and tubes,  $t: 2 \text{ mm} \leq t \leq 25 \text{ mm}$ , transverse to extruding direction**

<i>DNV GL Designation</i>	<i>Temper</i>	<i><math>f_1</math></i>
VL-6060	T5	0.51
VL-6061	T4 T5/T6	0.46 0.71
VL-6005A	T5/T6 $6 < t < 10$ $10 < t < 25$	0.76 0.67
VL-6082	T5 / T6	0.85

Note: Table 2 only applies when the main loading direction is longitudinal to the extrusion

**Table 4 Factor  $f_1$  in the welded condition**

<i>DNV GL Designation</i>	<i>Temper</i>	<i>Filler</i>	<i><math>f_1</math></i>
VL-5052	0, H111, H32, H34	5356	0.27
VL-5154A	0, H111	5356-5183	0.35
VL 5754	0, H111, H24	5356-5183	0.33
VL 5454	0, H111, H32, H34	5356-5183	0.35
VL-5086	0, H111, H116, H32, H34	5356-5183	0.42
VL-5083	H116, H321 H116, H321	5356 5183	0.53 <sup>1)</sup> 0.60 <sup>1)</sup>
VL-5383	H116, H34	5183	0.64 <sup>2)</sup>
VL-6060	T5	5356-5183	0.27
VL-6061	T4 T5/T6	5356-5183	0.48 0.48
VL-6063	T5 T6	5356-5183	0.27
VL-6005A	T5/T6	5356-5183	0.48
VL-6082	T4 T5/T6	5356-5183	0.46 0.48

1) The utilisation of the material is higher than given by the  $f_1$  factor as given in Sec.1 [1]. This is due to extended utilisation in Rules for HS, LC and NSC,  $f_1=(\sigma_1/240) \times 1.10$

2) The utilisation of the material is higher than given by the  $f_1$  factor as given in Sec.1 [1]. This is due to extended utilisation in Rules for HS, LC and NSC,  $f_1=(\sigma_1/240) \times 1.10$

## 3 Corrosion protection

### 3.1 General

**3.1.1** Loss of structural strength due to corrosion is not acceptable.

**3.1.2** All surfaces that are not recognised as inherently resistant to the actual marine environment are to be adequately protected against corrosion.

**Guidance note:**

In these rules, corrosion is defined as degradation of material due to environmental influence.

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### 3.2 For information and approval

**3.2.1** Selection and combination of materials for exposure to sea water and/or marine atmosphere are subject to approval.

**3.2.2** A sound anti-corrosion coating should always be combined with the anti-fouling coating on the external hull.

**3.2.3** Anti-corrosion coating is not to contain copper or other constituents that may cause galvanic corrosion on the aluminium hull.

**3.2.4** Hull integrated water ballast tanks and other tanks holding corrosive liquids are to be coated. All stiffeners and frames in these tanks are to be welded to plating with double continuous welding, see [Sec.8 \[2.2.2\]](#).

**3.2.5** In other internal compartments of the hull where corrosive water is likely to occur, the lower 0.5 m of the internal bottom surface, measured along the plate on each side of the keel, and the corresponding section of the bulkheads, is normally to be coated. The preparation of surfaces including welds and edges shall be such that the coating can be properly applied.

**Guidance note:**

The use of 6000 alloys containing more than 0.15% Cu in internal compartments without coating may be restricted.

Stagnant, chloride-containing water in internal compartments, e.g. condensation water, may cause corrosion on aluminium alloy plates and structures. Corrosion attacks will usually be of localised type, e.g. in the form of pitting. Corrosion attacks of galvanic type may also occur, see also [\[3.5\]](#), e.g. if equipment made of other metal alloy remains in electrical contact with aluminium alloy material.

Corrosion attacks of the above mentioned types can be reduced by means of e.g.:

- coating applied as described above
- regular cleaning, drying and inspection of the actual compartment
- electrical isolation of any other metallic part from aluminium alloy plates and structures
- use of dehumidifying equipment in a closed compartment
- ventilation holes (minimum 2)
- drainage holes
- hot air fans.

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### 3.3 Cathodic protection

**3.3.1** Cathodic protection of aluminium hulls can be obtained with aluminium or zinc sacrificial anodes or impressed current. Magnesium based sacrificial anodes are not to be used, and impressed current is not to be used in internal hull compartments.

**3.3.2** Cathodic protection is normally to be applied to aluminium hull craft due to electrical connection of the aluminium with another metals (in propeller, water jet, etc.), which may initiate galvanic corrosion, and to protect the hull against local corrosion and damage that normally will occur in protective coatings.

**Guidance note:**

The current density demand will vary dependent upon the speed of hull, the speed of propeller, and the type of metallic material to be protected (aluminium, stainless steel, etc.).

The target protective potential difference for aluminium alloy surfaces may be minus 950 mV versus the Ag/AgCl/seawater reference electrode, with an acceptable potential difference range of minus 800 mV to minus 1150 mV, i.e. approximately as for carbon steel and stainless steel. Due concern must be given to the possibility of detrimental overprotection of aluminium.

Stainless steel surfaces in water jet units of high speed craft may need a current density of up to about 300 mA/m<sup>2</sup> to be protected, while values as high as 500 mA/m<sup>2</sup> may give overprotection problems.

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**3.3.3** The designed (target) service life of a cathodic protection system is normally to be at least as long as the expected time interval between dockings.

**3.3.4** With impressed current cathodic protection systems, precautions are to be taken to avoid:

- 1) overprotection or excessive negative potential differences locally, especially on aluminium surfaces (implying transpassive corrosion) as well as
- 2) loss of protection,  
by means of anode screens, automatic voltage control, overprotection alarm, or similar. The protective potential difference is to be kept within a specified and agreed range, see Guidance note to [Sec.1 \[1.4.1\]](#).

**3.3.5** Direct voltage stray currents may impose rapid electrolytic corrosion damage to hulls and is to be avoided.

**Guidance note:**

Stray D.C. sources may be shore connections (e.g. ramps, cranes, cables, etc.), not properly grounded welding machines, etc. Special precautions should be taken if welding is carried out with the craft afloat, or if the craft is connected to electrical power in port.

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### 3.4 Other materials in contact with aluminium

**3.4.1** If other metallic materials are used in propellers or impellers, piping, pumps, valves, etc. and are in contact with the aluminium hull, provisions are to be made to avoid galvanic corrosion. Acceptable provisions are either one of or a combination of:

- coating of water or moisture exposed surfaces
- electrical isolation of different materials from each other
- cathodic protection.

**Guidance note:**

Full electrical isolation of e.g. propeller or impeller from hull is usually difficult. Contact will be established when the propeller is idle. Wooden material, cloth, debris, non-adherent coating or other organic material remaining in durable contact with aluminium may cause under-deposit corrosion on aluminium due to local oxygen deficiency at the surface.

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## 4 Other materials

### 4.1 Steel

**4.1.1** Structural steel may be used in sundry items such as rudders, foils, propeller shaft brackets, etc.

**4.1.2** For requirements for chemical composition, mechanical properties, heat treatment, testing and repair of defects, see [Pt.2](#).

**4.1.3** Design of steel structures shall be carried out in accordance with the relevant rule requirements of [Pt.2](#).

**4.1.4** All steel surfaces are to be protected against corrosion by paint of suitable composition or other effective coating.

**4.1.5** Shop primers applied over areas which will subsequently be welded, are to be of a quality accepted by the Society as having no detrimental effect on the finished weld.

See "Register of Approved Manufacturers" and "Register of Type Approved Products".

**4.1.6** Coating systems are to be suitable for use on any previously applied shop primer.

The coating and the assumed application conditions must have been approved by the Society. Such approval will normally be given as a «Type approval».

The shipbuilders are to present a written declaration stating that the coating has been applied as specified.

**Guidance note:**

Upon request approval programs for coating systems may be obtained from the Society.

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### 4.2 Connections between steel and aluminium

**4.2.1** If there is risk of galvanic corrosion, provisions are to be made, see [\[3.4\]](#).

**4.2.2** Aluminium plating connected to a steel boundary bar is wherever possible to be arranged on the side exposed to moisture.

**4.2.3** Direct contact between exposed wooden materials, e.g. deck planking, and aluminium is to be avoided.

**4.2.4** Bolts with nuts and washers are either to be of stainless steel or hot galvanized steel. The bolts are in general to be fitted with sleeves of insulating material.

### 4.3 Fibre Reinforced Plastic (FRP)

**4.3.1** FRP materials, core materials and fillers are to be approved according to [SHIP Pt.2 Ch.3 Sec.3](#).

**4.3.2** Other reinforcement and plastic materials may be approved on the basis of relevant documentation and testing in each individual case.

## SECTION 3 MANUFACTURING

### 1 General

#### 1.1 Basic requirements

**1.1.1** Welding of hull structures, machinery installations and equipment are to be carried out by approved welders, with approved welding consumables and at welding shops recognised by the Society, see [SHIP Pt.2 Ch.1](#).

**1.1.2** Shot blasting, priming and coating are to be carried out under indoor conditions. For coating specification and documentation, see [Sec.1](#).

### 2 Inspection

#### 2.1 General

**2.1.1** Welds are to be subject to visual survey and inspection as fabrication proceed. NDT is to be performed according to established procedures.

**2.1.2** All examinations are to be carried out by competent personnel. The NDT operators are to be qualified according to a recognised certification scheme accepted by the Society. The certificate is clearly to state the qualifications as to which examination method and within which category the operator is qualified.

#### 2.2 Penetrant testing

**2.2.1** Penetrant testing is to be carried out as specified in the approved procedures.

#### 2.3 Radiographic testing

**2.3.1** Radiographic testing is to be carried out as specified in the approved procedures.

**2.3.2** Processing and storage are to be such that the films maintain their quality throughout the agreed storage time. The radiographs are to be free from imperfections due to development processing.

#### 2.4 Ultrasonic examination

**2.4.1** Ultrasonic testing is to be carried out as specified in the approved procedures. Ultrasonic examination procedures are to contain sketches for each type of joint and dimensional range of joints which clearly show scanning pattern and probes to be used.

**2.4.2** The examination record is to include the imperfection position, the echo height, the dimensions (length), the depth below the surface and, if possible, the defect type.

### 3 Extent of examination

#### 3.1 General

**3.1.1** All welds are to be subject to visual examination. In addition to the visual examination, at least 2% to 5% of total welded length are to be examined by penetrant examination and/or radiographic examination. For highly stressed areas the extent of examination may be increased.

**3.1.2** If defects are detected, the extent of examination is to be increased to the surveyor's satisfaction.

### 4 Acceptance criteria for NDT

#### 4.1 Acceptance criteria

**4.1.1** All welds are to show evidence of good workmanship. The quality is normally to comply with ISO 10042 quality level C, intermediate. For highly stressed areas more stringent requirements, such as ISO level B, may be applied.

### 5 Testing

#### 5.1 Tanks

**5.1.1** Protective coating systems may be applied before water testing.

All pipe connections to tanks are to be fitted before testing. If engine bed plates are bolted directly on the inner bottom plating, the testing of the double bottom tank is to be carried out with the engine installed.

**5.1.2** Unless otherwise agreed, all tanks are to be tested with a water head equal to the maximum pressure to which the compartment may be exposed. The water is in no case to be less than to the top of the air pipe or to a level  $h_0$  above the top of the tank except where partial filling alone is prescribed.

$h_0 = 0.03 L - 0.5$  (m), minimum 1, generally  
= pressure valve opening pressure when exceeding the general value.

#### 5.2 Closing appliances

**5.2.1** Inner and outer doors below the waterline are to be hydraulically tested.

**5.2.2** Weathertight and watertight closing appliances not subjected to pressure testing are to be hose tested. The nozzle inside diameter is to be 12.5 mm and the pressure at least  $250 \text{ kN/m}^2$ . The nozzle should be held at a distance of maximum 1.5 m from the item during the test.

Alternative methods of tightness testing may be considered.

**5.2.3** All weathertight or watertight doors and hatches are to be function tested.

## SECTION 4 HULL GIRDER STRENGTH

### 1 General

#### 1.1 Introduction

**1.1.1** In this section requirements for longitudinal and transverse hull girder strength are given. In addition, buckling control according to [Sec.10](#) may be required.

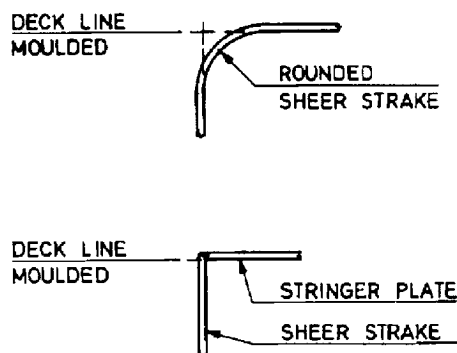
**1.1.2** Longitudinal strength has generally to be checked for the craft types and sizes mentioned in the introduction to [Ch.1 Sec.3](#).

**1.1.3** For new designs (prototypes) of large and structurally complicated craft (e.g. multi-hull types) a complete 3-dimensional global analysis of the transverse strength, in combination with longitudinal stresses, is to be carried out.

**1.1.4** Buckling strength in bottom and deck may, however, have to be checked also for the other craft.

#### 1.2 Definitions

**1.2.1** *Moulded deck line, Rounded sheer strake, Sheer strake and Stringer plate* are as defined in [Figure 1](#).



**Figure 1 Deck corners**

## 2 Vertical bending strength

### 2.1 Hull section modulus requirement

$$Z = \frac{M}{\sigma} \times 10^3 \quad (cm^3)$$

$M$  = the longitudinal midship bending moment in kNm from [Ch.1 Sec.4](#)  
 = sagging or hogging bending moment  
 = hollow landing or crest landing bending moment  
 = maximum still water + wave bending moment for high speed displacement craft and semi-planing craft in the displacement mode  
 = maximum total moment for hydrofoil on foils  
 $\sigma$  =  $175 f_1 \text{ N/mm}^2$  in general.

**Guidance note:**

Simultaneous end impacts over a hollow are considered less frequent and giving lower moments than the crest landing.  
 Need not be investigated if deck buckling resistance force is comparable to that of the bottom.

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### 2.2 Effective section modulus

**2.2.1** Where calculating the moment of inertia and section modulus of the midship section, the effective sectional area of continuous longitudinal strength members is in general the net area after deduction of openings.

Superstructures which do not form a strength deck are not to be included in the net section. This applies also to deckhouses and bulwarks.

**2.2.2** The effect of openings are assumed to have longitudinal extensions as shown by the shaded areas in [Figure 2](#), i.e., inside tangents at an angle of  $30^\circ$  to each other. Example for transverse section III:

$$b_{III} = b' + b'' + b'''$$

**2.2.3** For twin hull vessels the effective breadth of wide decks without longitudinal bulkhead support will be considered separately.

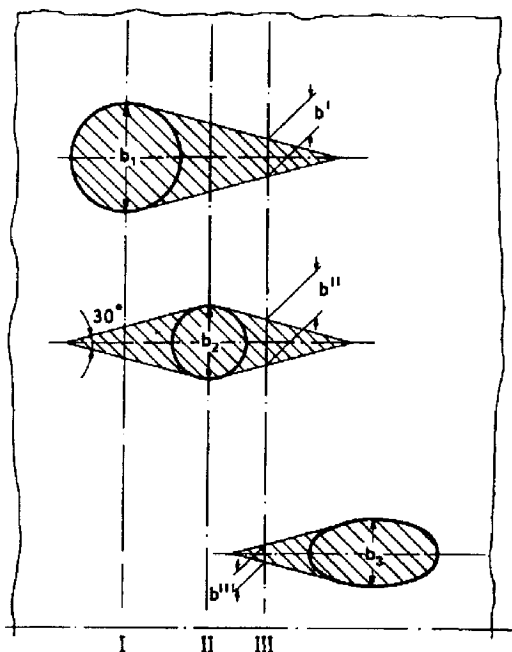
### 2.3 Hydrofoil on foils

**2.3.1** For hydrofoils in addition to the calculation for the midship section, the sections in way of the foils are required to be checked.

### 2.4 Longitudinal structural continuity

**2.4.1** The scantling distribution of structures participating in the hull girder strength in the various zones of the hull is to be carefully worked out so as to avoid structural discontinuities resulting in abrupt variations of stresses.

**2.4.2** At ends of effective continuous longitudinal strength members in deck and bottom region large transition brackets are to be fitted.



**Figure 2 Effect of openings**

## 2.5 Openings

**2.5.1** A keel plate for docking is normally not to have openings. In the bilge plate, within 0.5 L amidships, openings are to be avoided wherever practicable. Any necessary openings in the bilge plate are to be kept clear of a bilge keel.

**2.5.2** Openings in strength deck are wherever practicable to be located well clear of the craft's side and hatch corners.

**2.5.3** Openings in strength members should generally have an elliptical form. Larger openings in deck may be accepted with well rounded corners and are to be situated as near to the craft's centerline as practicable.

**2.5.4** For corners with rounded shape the radius is not to be less than:

$$r = 0.025 B_{dk} \text{ (m)}$$

$B_{dk}$  = breadth of strength deck.

$r$  need not be taken greater than 0.1  $b$  (m) where  $b$  = breadth of opening in m. For local reinforcement of deck plating at circular corners, see [Sec.5 \[2\]](#).

**2.5.5** Edges of openings are to be smooth. Machine flame cut openings with smooth edges may be accepted. Small holes are to be drilled.

**2.5.6** Studs for securing small hatch covers are to be fastened to the top of a coaming or a ring of suitable thickness weld to the deck. The studs are not to penetrate the deck plating.

### 3 Shear strength

#### 3.1 Cases to be investigated

**3.1.1** If doors are arranged in the craft's side, the required sectional area of the remaining side plating will be specially considered.

**3.1.2** If rows of windows are arranged below strength deck, sufficient horizontal shear area must be arranged to carry down the midship tension and compression.

**3.1.3** In these and other locations with doubtful shear areas, allowable shear stress may be taken as:

$$\tau = (\text{allowable bending stress})/\sqrt{3}$$

### 4 Cases to be Investigated

#### 4.1 Inertia induced loads

**4.1.1** Transversely stiffened parts of forebody are to be checked for the axial inertia force given in [Ch.1 Sec.3 \[1.7\]](#):

$$F_L = \Delta a_l \text{ (kN)}$$

$a_l$  = maximum surge acceleration, not to be taken less than:

0.4 g for  $V/\sqrt{L} \geq 5$

0.2 g for  $V/\sqrt{L} \leq 3$

linear interpolation of  $a_l$  for  $3 < V/\sqrt{L} < 5$

The distribution of stresses will depend on instantaneous forward immersion and on location of cargo.

**4.1.2** Bottom structure in way of thrust bearings may need a check for the increased thrust when vessel is retarded by a crest in front.

**4.1.3** Allowable axial stress and associated shear stresses will be related to the stresses already existing in the region.

**4.1.4** For passenger craft, a separate analysis is to be performed to investigate the structural consequence when subject to the collision load as given in the International Code of Safety for High-Speed Craft, paragraph [\[4.3\]](#).

**Guidance note:**

Inertia forces from the collision deceleration should be considered for shear and buckling in the foreship area, and for the forces acting on the supporting structure for cargo.

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## 5 Transverse strength of twin hull craft

### 5.1 Transverse strength

**5.1.1** The twin hull connecting structure is to have adequate transverse strength related to the design loads and moments given in [Ch.1](#).

**5.1.2** When calculating the moment of inertia, and section modulus of the longitudinal section of the connecting structure, the effective sectional area of transverse strength members is in general to be taken as the net area with effective flange after deduction of openings.

The effective shear area of transverse strength members is in general to be taken as the net web area after deduction of openings.

### 5.2 Allowable stresses

**5.2.1** The equivalent stress is defined as:

$$\sigma_c = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3\tau^2}$$

$\sigma_x$  = total normal stress in x-direction  
 $\sigma_y$  = total normal stress in y-direction  
 $\tau$  = total shear stress in the xy-plane.

By total stress is meant the arithmetic sum of stresses from hull girder and local forces and moments.

**5.2.2** The following total stresses are normally acceptable:

— normal stress:

$$\sigma = 160 f_1 \text{ (N/mm}^2\text{)}$$

— mean shear stress:

$$\tau = 90 f_1 \text{ (N/mm}^2\text{)}$$

— equivalent stress:

$$\sigma_e = 180 f_1 \text{ (N/mm}^2\text{)}.$$

## SECTION 5 PLATING AND STIFFENERS

### 1 General

#### 1.1 Introduction

##### 1.1.1

In this section the general requirements for plate thicknesses and local strength of panels of aluminium alloy are given.

##### 1.1.2

Buckling strength requirements are related to longitudinal hull girder stresses. Panels subjected to other compressive, shear or biaxial stresses will be specially considered.

**Table 1 Allowable bending stresses**

Item	Plate	Stiffener
	$(N/mm^2)$	
Bottom, slamming load	$200 f_1$	$180 f_1$
Bottom, sea load	$180 f_1$	$160 f_1$
Side	$180 f_1$	$160 f_1$
Deck	$180 f_1$	$160 f_1$
Flat cross structure, slamming load	$200 f_1$	$180 f_1$
Flat cross structure, sea load	$180 f_1$	$160 f_1$
Bulkhead, collision	$180 f_1$	$160 f_1$
Superstructure/deckhouse front	$160 f_1$	$140 f_1$
Superstructure/deckhouse side/deck	$180 f_1$	$160 f_1$
Bulkhead, watertight	$220 f_1$	$200 f_1$
Tank bulkhead	$180 f_1$	$160 f_1$

#### 1.2 Definitions

##### 1.2.1 Symbols:

- $t$  = rule thickness of plating in mm
- $Z$  = rule section modulus of stiffener in  $cm^3$
- $s$  = stiffener spacing in m, measured along the plating
- $l$  = stiffener span in m, measured along the top flange of the member. The depth of stiffener on crossing panel may be deducted when deciding the span. For curved stiffeners  $l$  may be taken as the chord length.
- $p$  = design pressure in  $kN/m^2$  as given in [Ch.1 Sec.3 \[3\]](#)
- $\sigma$  = nominal allowable bending stress in  $N/mm^2$  due to lateral pressure (see [Table 1](#))
- $f_1$  = see [Sec.2 \[2.2.4\]](#)
- $\tau$  = nominal allowable shear stress in  $N/mm^2$

## 1.3 Allowable stresses

**1.3.1** Maximum allowable bending stresses in plates and stiffeners are to be according to [Table 1](#).

## 2 Plating

### 2.1 Minimum thicknesses

**2.1.1** The thickness of structures shall in general not be less than:

$$t = \frac{t_0 + kL}{\sqrt{f}} \frac{s}{S_R} \quad (\text{mm})$$

where:

- $f$  =  $\sigma_f/240$   
 $\sigma_f$  = yield stress in N/mm<sup>2</sup> at 0.2% offset for unwelded alloy  
 $\sigma_f$  is not to be taken greater than 70% of the ultimate tensile strength  
 $s$  = actual stiffener spacing [m]  
 $S_R$  = basic stiffener spacing [m]  
 $= 2(100 + L)/1000$

$S/S_R$  shall not be taken less than 0.5 or greater than 1.0.

$t_0$  and  $k$  according to [Table 2](#).

**Table 2 Values of  $t_0$  and  $k$**

	Item	$t_0$	$k$
<i>Shell plating</i>	Bottom, bilge and side to loaded water line	4.0	0.03
	Side above loaded water line	3.5	0.02
	Bottom aft in way of rudder, shaft brackets etc.	10.0	0.10
<i>Deck and inner bottom plating</i>	Strength deck weather part forward of amidships	3.0	0.03
	Strength deck weather part aft of amidships	2.5	0.02
	Inner bottom	3.0	0.03
	Car deck	4.0	0.03
	Accommodation deck	2.0	0.02
	Deck for cargo	4.0	0.03
	Superstructure and deckhouse decks	1.0	0.01
<i>Bulkhead plating</i>	Collision bulkhead	3.0	0.03
	Tank bulkhead	3.0	0.03

	Item	$t_0$	$k$
	Other watertight bulkheads	3.0	0.02
	Superstructure and deckhouse front	3.0	0.01
	Superstructure and deckhouse sides and aft	2.5	0.01
Other structures	Foundations	3.0	0.08
	Structures not mentioned above	3.0	0

## 2.2 Bending

**2.2.1** The general requirement for thickness of plating subject to lateral pressure is given by:

$$t = \frac{s\sqrt{Cp}}{\sqrt{\sigma}} \text{ (mm)}$$

$C$  = correction factor for aspect ratio ( $= s/l$ ) of plate field and degree of fixation of plate edges given in [Table 3](#).

**2.2.2** The thickness requirement for a plate field clamped along all edges and with an aspect ratio  $\leq 0.5$ :

$$t = \frac{22.4s\sqrt{p}}{\sqrt{\sigma}} \text{ (mm)}.$$

## 2.3 Slamming

**2.3.1** The bottom plating is to be strengthened according to the requirements given in [\[2.3.2\]](#) to [\[2.3.3\]](#).

**2.3.2** The thickness of the bottom plating is not to be less than:

$$t = \frac{22.4k_r k_a s \sqrt{P_{sl}}}{\sqrt{\sigma_{sl}}} \text{ (mm)}$$

where:

- $k_a$  = correction factor for aspect ratio of plate field
- =  $(1.1 - 0.25 s/l)^2$
- = maximum 1.0 for  $s/l = 0.4$
- = minimum 0.72 for  $s/l = 1.0$

$k_r$  = correction factor for curved plates

$$= \left(1 - 0.5 \frac{s}{r}\right)$$

$r$  = radius of curvature in m

$P_{sl}$  = as given in [Ch.1 Sec.3](#)

$\sigma_{sl}$  = 200  $f_1$  (N/mm<sup>2</sup>).

**2.3.3** Above the slamming area the thickness may be gradually reduced to the ordinary requirement at side. For craft with rise of floor, however, reduction will not be accepted below the bilge curvature or chine.

**Table 3 Values of C**

Degree of fixation of plate edges	Aspect ratio < 0.5				Aspect ratio = 1.0			
	$\sigma_l$	$\sigma_s$	$\sigma_x$	$\sigma_y$	$\sigma_l$	$\sigma_s$	$\sigma_x$	$\sigma_y$
Clamped along all edges	500	342	75	250	310	310	130	130
Longest edge clamped, shortest edge simply supported	500	0	75	250	425	0	140	200
$\sigma_l$ = stress at midpoint of longest edge. $\sigma_s$ = stress at midpoint of shortest edge. $\sigma_x$ = maximum field stress parallel to longest edge. $\sigma_y$ = maximum field stress parallel to shortest edge.								

## 3 Stiffeners

### 3.1 Bending

**3.1.1** The section modulus of longitudinals, beams, frames and other stiffeners subjected to lateral pressure is not to be less than:

$$Z = \frac{m l^2 s p}{\sigma} \quad (cm^3)$$

$m$  = bending moment factor depending on degree of end constraints and type of loading, see also [Sec.6 Table 5](#).

The m-values are normally to be as given in [Table 4](#).

The m-values may have to be increased after special consideration of rotation/deflection at supports or variation in lateral pressure.

The m-values may be reduced, provided acceptable stress levels are demonstrated by direct calculations.

**3.1.2** The requirement in [3.1.1] is to be regarded as a requirement about an axis parallel to the plating. As an approximation, the requirement for standard section modulus for stiffeners at an oblique angle with the plating may be obtained if the formula in [3.1.1] is multiplied by the factor:

$$1/\cos \alpha$$

$\alpha$  = angle between the stiffener web plane and the plane perpendicular to the plating.

For  $\alpha$ -values less than 12° corrections are normally not necessary.

**3.1.3** When several members are equal, the section modulus requirement may be taken as the average requirement for each individual member in the group. However, the requirement for the group is not to be taken less than 90% of the largest individual requirement.

**3.1.4** Front stiffeners of superstructures and deckhouses are to be connected to deck at both ends with a connection area not less than:

$$a = \frac{0.07}{f_1} l_{sp} \quad (cm^2)$$

Side and after end stiffeners in the lowest tier of erections are to have end connections.

**Table 4 Values of m**

<i>Item</i>	<i>m</i>
Continuous longitudinal members	85
Non-continuous longitudinal members	100
Transverse members	100
Vertical members, ends fixed	100
Vertical members, simply supported	135
Bottom longitudinal members	85
Bottom transverse members	100
Side longitudinal members	85
Side vertical members	100
Deck longitudinal members	85
Deck transverse members	100
Watertight bulkhead stiffeners, fixed ends	65
Watertight bulkhead stiffeners, fixed one end (lower)	85
Watertight bulkhead stiffeners, simply supported ends	125
Watertight bulkhead horizontal stiffeners, fixed ends	85
Watertight bulkhead stiffeners, fixed one end (upper)	75
Watertight bulkhead horizontal stiffeners, simply supported	125

Item	<i>m</i>
Tank cargo bulkhead, fixed ends	100
Tank cargo bulkhead, simply supported	135
Deckhouse stiffeners	100
Casing stiffeners	100

## 3.2 Slamming

**3.2.1** The section modulus of longitudinals or transverse stiffeners supporting the bottom plating is not to be less than:

$$Z = \frac{m l^2 s p_{sl}}{\sigma_{sl}} \quad (cm^3)$$

*m* = 85 for continuous longitudinals  
 = 100 for transverse stiffeners  
*p<sub>sl</sub>* = slamming pressure as given in Ch.1 Sec. 2  
*σ<sub>sl</sub>* = 180 *f<sub>1</sub>* (N/mm<sup>2</sup>).

The shear area is not to be less than:

$$A_s = \frac{6.7(l-s)s p_{sl}}{\tau_{sl}} \quad (cm^2)$$

*τ<sub>sl</sub>* = 90 *f<sub>1</sub>* (N/mm<sup>2</sup>).

## SECTION 6 WEB FRAMES AND GIRDER SYSTEMS

### 1 General

#### 1.1 Introduction

**1.1.1** In this section the general requirements for simple girders and procedures for the calculations of complex girder systems are given.

#### 1.2 Definitions

##### 1.2.1 Symbols:

$s$	= girder span in m. The web height of in-plane girders may be deducted
$b$	= breadth of load area in m (plate flange) $b$ may be determined from <a href="#">Table 1</a>
$p$	= design pressure in $\text{kN/m}^2$ according to <a href="#">Ch.1 Sec.3</a>
$P$	= design axial force in kN
$\sigma$	= nominal allowable bending stress in $\text{N/mm}^2$ due to lateral pressure
$\tau$	= nominal allowable shear stress in $\text{N/mm}^2$
$\sigma_c$	= critical buckling stress in $\text{N/mm}^2$
$\sigma_{el}$	= ideal elastic buckling stress in $\text{N/mm}^2$
$Z$	= rule section modulus in $\text{cm}^3$
$A_W$	= rule web area in $\text{cm}^2$
$A$	= rule cross-sectional area in $\text{cm}^2$
$t_w$	= web thickness in mm
$h_w$	= web height in mm
$b_f$	= flange breadth in mm.

#### 1.3 Minimum thicknesses

**1.3.1** The thickness of structures are in general not to be less than:

$$t = \frac{t_0 + kL}{\sqrt{f}} \frac{s}{s_R} \quad (\text{mm})$$

$f$	= $\sigma_f / 240$
$\sigma_f$	= yield stress in $\text{N/mm}^2$ at 0.2% offset for unwelded alloy. $\sigma_f$ is not to be taken greater than 70% of the ultimate tensile strength. For unwelded material, $f$ may be taken as $f_1$ in <a href="#">Sec.2 Table 1</a> to <a href="#">Sec.2 Table 3</a> .
$s$	= actual stiffener spacing in m
$s_R$	= basic stiffener spacing in m = $2(100 + L)/1000$

$s/s_R$  is not to be taken less than 0.5 or greater than 1.0.

$t_0$  and  $k$  according to [Table 2](#).



**Table 1 Breadth of load area**

For ordinary girders	$b = 0.5 (l_1 + l_2) \text{ (m)}$ $l_1$ and $l_2$ are the spans in m of the supported stiffeners
For hatch side coamings	$b = 0.2 (B_1 - b_2) \text{ (m)}$ $B_1$ = breadth of craft in m measured at the middle of the hatchway $b_2$ = breadth of hatch in m measured at the middle of the hatchway
For hatch end beams	$b = 0.4 b_3 \text{ (m)}$ $b_3$ = distance in m between hatch end beam and nearest deep transverse girder or transverse bulkhead

**Table 2 Values of  $t_0$  and  $k$** 

<i>Item</i>		$t_0$	$k$
<i>Girders and stiffeners</i>	Bottom centre girder	3.0	0.05
	Bottom side girders, floors, brackets and stiffeners	3.0	0.03
	Side, deck and bulkhead longitudinals girders and stiffeners outside the peaks	3.0	0.02
	Peak girders and stiffeners	3.0	0.03
	Longitudinals	3.0	0.03
	Double bottom floors and girders	3.0	0.02
<i>Other structures</i>	Foundations	3.0	0.08
	Structures not mentioned above	3.0	0

## 1.4 Allowable stresses

**1.4.1** Maximum allowable bending stresses and shear stresses in web frames and girders are to be according to Table 3.

**Table 3 Allowable stresses**

<i>Item</i>	<i>Web frames and girders</i>		
	<i>Bending stress (N/mm<sup>2</sup>)</i>	<i>Shear stress (N/mm<sup>2</sup>)</i>	<i>Equivalent stress (N/mm<sup>2</sup>)</i>
Dynamic load	180 $f_1$	90 $f_1$	200 $f_1$
Sea/static load	160 $f_1$	90 $f_1$	180 $f_1$

For watertight bulkheads (excluding the collision bulkhead), allowable stresses may be increased to 200  $f_1$ , 100  $f_1$  and 220  $f_1$  for bending, shear and equivalent stresses, respectively.

## 1.5 Continuity of strength members

**1.5.1** Structural continuity is to be maintained at the junction of primary supporting members of unequal stiffness by fitting well rounded brackets.

Brackets are to extend to the nearest stiffener, or local plating reinforcement is to be provided at the toe of the bracket.

**1.5.2** Where practicable, deck pillars are to be located in line with pillars above or below.

## 2 Web frames and primary structure elements

### 2.1 General

**2.1.1** The requirements for section modulus and web area given in [2.4] are applicable to simple girders supporting stiffeners or other girders exposed to linearly distributed lateral pressure. It is assumed that the girder satisfies the basic assumptions of simple beam theory and that the supported members are approximately evenly spaced and similarly supported at both ends. Other loads will have to be specially considered.

**2.1.2** When boundary conditions for individual girders are not predictable due to dependence of adjacent structures, direct calculations according to the procedures given in Sec.9 [4] will be required.

**2.1.3** The section modulus and web area of the girder are to be taken in accordance with requirements as given in the following. Structural modelling in connection with direct stress analysis is to be based on the same requirements when applicable. Note that such structural modelling will not reflect the stress distribution at local flange cutouts or at supports with variable stiffness over the flange width. The local effective flange which may be applied in stress analysis is indicated for construction details in various Classification Notes on «strength analysis of hull structures».

### 2.2 Effective flange

**2.2.1** The effective plate flange area is defined as the cross-sectional area of plating within the effective flange width. Continuous stiffeners may be included with 50% of their cross-sectional area. The effective flange width  $b_e$  is determined by the following formula:

$$b_e = C \cdot b \text{ (m)}$$

$C$  = as given in Table 4 for various numbers of evenly spaced point loads ( $r$ ) on the span.

If the above method of calculation is used for strength members that support corrugations perpendicular to the span of the strength member,  $C$  is to be reduced by 90%.

**Table 4 Values of C**

$a/b$	0	1	2	3	4	5	6	$\geq 7$
$C (r \geq 6)$	0.00	0.38	0.67	0.84	0.93	0.97	0.99	1.00
$C (r = 5)$	0.00	0.33	0.58	0.73	0.84	0.89	0.92	0.93
$C (r = 4)$	0.00	0.27	0.49	0.63	0.74	0.81	0.85	0.87
$C (r \leq 3)$	0.00	0.22	0.40	0.52	0.65	0.73	0.78	0.80

$a$  = distance between points of zero bending moments  
 =  $S$  for simply supported girders  
 =  $0.6 S$  for girders fixed at both ends.

**2.2.2** The effective plate area is not to be less than the effective area of the free flange within the following regions:

- ordinary girders: total span
- continuous hatch side coamings and hatch end beams: length and breadth of the hatch, respectively, and an additional length of 1 m at each end of the hatch corners.

## 2.3 Effective web

**2.3.1** Holes in girders will generally be accepted, provided the shear stress level is acceptable and the buckling strength is sufficient. Holes are to be kept well clear of end of brackets and locations where shear stresses are high.

## 2.4 Strength requirements

**2.4.1** The section modulus for girders subjected to lateral pressure is not to be less than:

$$Z = \frac{mS^2bp}{\sigma} \quad (cm^3)$$

$\sigma$  = 160  $f_1$  (maximum)

$m$  = bending moment factor,  $m$ -values in accordance with [2.4.3] may be applied.

**2.4.2** The effective web area of girders subjected to lateral pressure is not to be less than:

$$A_W = \frac{10(k_s Sbp - ar)}{\tau} \quad (cm^2)$$

$k_s$  = shear force factor.

=  $k_s$ -values in accordance with [2.4.3] may be applied

$a$  = number of stiffeners between considered section and nearest support

$r$  = average point load in kN from stiffeners between considered section and nearest support







$\tau$  = 90  $f_1$  (maximum).

The  $a$ -values shall in no case be taken greater than  $(n + 1)/4$ .

$n$  = number of supported stiffeners on the girder span. The web area at the middle of the span is not to be less than 0.5  $A_W$ .

**2.4.3** The  $m$ - and  $k_s$ -values referred to in [2.4.1] and [2.4.2] may be calculated according to general beam theory. In Table 5  $m$ - and  $k_s$ -values are given for some defined load and boundary conditions. Note that the greatest  $m$ -value is to be applied to simple girders. For girders where brackets are fitted or the flange area has been partly increased due to large bending moment, a smaller  $m$ -value may be accepted outside the strengthened region.

**Table 5 Values of  $m$  and  $k_s$** 

Load and boundary conditions			Bending moment and shear force factors		
Positions			1	2	3
1 Support	2 Field	3 Support	$m_1$ $ks_1$	$m_2$ —	$m_3$ $ks_3$
			85 0.50	42	85 0.50
			0.38	70	1.25 0.63
			0.50	125	0.50
			65 0.30	43	100 0.70
			0.20	60	135 0.80
			0.33	130	0.67

**2.4.4** The  $m$ - and  $k_s$ -values referred to in [2.4.1] and [2.4.2] are normally to be as given in Table 6 for the various structural items.

**Table 6 Values of  $m$  and  $ks$  for various structural items**

<i>Item</i>		<i>m</i>	<i>ks</i>
Bottom:	Web frames	100	0.63
	Floors	100	0.63
	Longitudinal girders	100	0.63
Side:	Longitudinal girders	100	0.54
	Web frames, upper end	100	0.54
	Web frames, lower end	100	0.72
	Deck girders	100	0.63
Bulkhead:	Horizontal girders	100	0.54
	Vertical girders, upper end	100	0.54
	Vertical girders, lower end	100	0.72

**2.4.5** The equivalent stress is not to exceed  $180 f_1 \text{ N/mm}^2$ .

## 2.5 Girder tripping brackets

**2.5.1** The spacing  $S_T$  of tripping brackets is normally not to exceed the values given in Table 7 valid for girders with symmetrical face plates. For others the spacing will be specially considered.

Tripping brackets are further to be fitted near the toe of bracket, near rounded corner of girder frames and in line with any cross ties.

**2.5.2** The tripping brackets are to be fitted in line with longitudinals or stiffeners, and are to extend the whole height of the web plate. The arm length of the brackets along the longitudinals or stiffeners, is not to be less than 40% of the depth of the web plate, the depth of the longitudinal or stiffener deducted. The requirement may be modified for deep transverses.

**2.5.3** Tripping brackets on girders are to be stiffened by a flange or stiffener along the free edge if the length of the edge exceeds:

$$0.06 t_t \text{ (m)}$$

$t_t$  = thickness in mm of tripping bracket.

The area of the stiffening is not to be less than:

$$10 l_t \text{ (cm}^2\text{)}$$

$l_t$  = length in m of free edge.

The tripping brackets are to have a smooth transition to adjoining longitudinals or stiffeners exposed to large longitudinal stresses.

**Table 7 Spacing between tripping brackets**

Girder type	$S_T$ (m)
Bottom and deck transverses	0.02 $b_f$ maximum 6
Stringers and vertical webs in general	
Longitudinal girders in general	
Longitudinal girders in bottom and strength deck for L > 50m within 0.5 L amidships	0.014 $b_f$ maximum 4
Stringers and vertical webs in tanks and machinery spaces	
Vertical webs supporting single bottom girders and transverses	
If the web of a strength member forms an angle with the perpendicular to the ship's side of more than 10°, $S_T$ is not to exceed 0.007 $b_f$ . $b_f$ = flange breadth in mm $S$ = distance between transverse girders in m.	

## 2.6 Girder web stiffeners

**2.6.1** The web plate of transverse and vertical girders are to be stiffened where:

$$h_w > 75 t_w \text{ (mm)}$$

$t_w$  = web thickness in mm,

with stiffeners of maximum spacing:

$$s = 60 t_w \text{ (mm)}$$

within 20% of the span from each end of the girder and where high shear stresses.

Elsewhere stiffeners are required when:

$$h_w > 90 t_w \text{ (mm)}$$

with stiffeners of maximum spacing:

$$s = 90 t_w \text{ (mm)}$$

For girders supporting other girders, the end requirements may have to be applied all over the span.

**2.6.2** Stiffeners are to be fitted along free edges of the openings parallel to the vertical and horizontal axis of the opening. Stiffeners may be omitted in one direction if the shortest axis is less than 400 mm and in both directions if length of both axes is less than 300 mm. Edge reinforcement may be used as an alternative to stiffeners.

## SECTION 7 PILLARS AND PILLAR BULKHEADS

### 1 General

#### 1.1 Introduction

**1.1.1** In this section requirements for pillars and for bulkhead stiffeners substituting pillars are given.

#### 1.2 Definitions

**1.2.1** Symbols:

$L, B, D, T, C_B$ , see [Ch.1](#).

$t$  = thickness of plating in mm

$s$  = stiffener spacing in m, measured along plate

$l$  = length of pillars, cross ties, bulkhead stiffeners etc. between effective supports normal to their axis in m

$I$  = smallest moment of inertia in  $\text{cm}^4$ , including 40 x plate thickness as flange for bulkhead stiffener

$A$  = cross-sectional area in  $\text{cm}^2$ , including 40 x plate thickness for bulkhead stiffener

$p$  = design pressure as given in [Ch.1](#).

### 2 Pillars

#### 2.1 Arrangement of pillars

**2.1.1** Where practicable, deck pillars are to be located in line with pillars above or below.

If arrangement with pillars in line is not possible, primary structure elements will have to be reinforced.

**2.1.2** Pillars or equivalent supports are to be arranged below deckhouses, windlasses, winches and other heavy weights.

**2.1.3** The engine room casing is to be supported.

**2.1.4** Doublers are to be fitted on deck and inner bottom. When pillars are subject to tension loads, mainly in tanks, doublers are not allowed, adequate diamond plates with increased thickness to be fitted as inserts on girder-/beam flanges. Brackets may be used instead of doublers and diamond plates.

**2.1.5** Structural reinforcement below pillars will be considered in the individual cases.

## 2.2 Cross-section particulars

**2.2.1** The radius of gyration of a member is to be taken as:

$$i = \sqrt{\frac{I_a}{A_a}} \quad (cm)$$

$I_a$  = moment of inertia as built in  $cm^4$  about the axis perpendicular to the expected direction of buckling  
 $A_a$  = cross-sectional area as built in  $cm^2$ .

If the end conditions are different with respect to the principle axes of the member, the  $i$ -value may have to be checked for both axes.

## 2.3 Pillar scantlings

**2.3.1** The cross-sectional area of members subjected to compressive loads is not to be less than:

$$A = \frac{10 P}{\eta \sigma_c} \quad (cm^2)$$

$$\eta = \frac{k}{\left(1 + \frac{l}{i}\right)} \text{ minimum } 0.3$$

$P$  = axial load in kN as given for various strength members in [2.3.2] and [2.3.3]. Alternatively,  $P$  may be obtained from direct stress analysis. See Sec.9 [4]

$l$  = length of member in m

$i$  = radius of gyration in cm

$k$  = 0.7 in general

= 0.6 when design loads are primarily dynamic

$$\sigma_c = \sigma_E \text{ when } \sigma_E < \frac{\sigma_F}{2}$$

$$= \sigma_F \left(1 - \frac{\sigma_F}{4\sigma_E}\right) \text{ when } \sigma_E > \frac{\sigma_F}{2}$$

$$\sigma_E = p^2 E \left(\frac{i}{100 l}\right)^2 (N/mm^2)$$

$\sigma_F$  = minimum upper yield stress of material in  $N/mm^2$

$E$  = modulus of elasticity for aluminium = 69 000  $N/mm^2$ .

The formula given for  $\sigma_E$  is based on hinged ends and axial force only.

If, in special cases, it is verified that one end can be regarded as fixed, the value of  $\sigma_E$  may be multiplied by 2.

If it is verified that both ends can be regarded as fixed, the value of  $\sigma_E$  may be multiplied by 4.



In case of eccentric force additional end moments or additional lateral pressure, the strength member is to be reinforced to withstand bending stresses.

**2.3.2** The nominal axial force in pillars is normally to be taken as:

$$P = n \cdot F$$

$n$  = number of decks above pillar. In case of a large number of decks ( $n > 3$ ), a reduction in  $P$  will be considered based upon a special evaluation of load redistribution

$F$  = the force contribution in kN from each deck above and supported by the pillar in question given by:

$$F = p \cdot A_D \text{ (kN)}$$

$p$  = design pressure on deck as given in [Ch.1 Sec.3](#)

$A_D$  = deck area in  $m^2$  supported by the pillar, normally taken as half the sum of span of girders supported, multiplied by their loading breadth.

For centre line pillars supporting hatch end beams (see [Figure 1](#) and [Figure 2](#)):

$$A_D = 4(A_1 + A_2) \frac{b_1}{B} \text{ when transverse beams}$$

$$= 4(A_3 + A_4 + A_5) \frac{b_1}{B} \text{ when longitudinal}$$

$b_1$  = distance from hatch side to craft's side.

**2.3.3** The nominal axial force in cross ties and panting beams is normally to be taken as:

$$P = e \cdot b \cdot p \text{ (kN)}$$

$e$  = mean value of spans in m on both sides of the cross tie

$b$  = load breadth in m

$p$  = the larger of the pressures in  $kN/m^2$  on either side of the cross tie (e.g. for a side tank cross tie, the pressure head on the craft's side may be different from that on the longitudinal bulkhead).

## 2.4 Pillars in tanks

**2.4.1** Pillars made from hollow sections are not allowed inside tanks.

**2.4.2** Where the hydrostatic pressure may give tensile stresses in the pillars and cross members, their sectional area is not to be less than:

$$A = 0.07 A_{dk} \cdot p_t \text{ (cm}^2\text{)}$$

$A_{dk}$  = deck or side area in  $m^2$  supported by the pillar or cross member

$p_t$  = design pressure,  $p$  in  $kN/m^2$  giving tensile stress in the pillar.

The formula may be used also tension control of panting beams and cross ties in tanks.

Doubling plates at ends are not allowed.

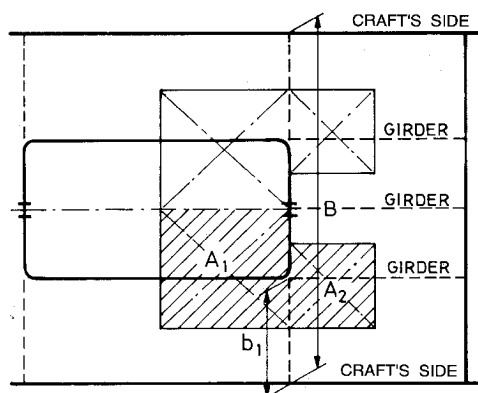
## 3 Supporting bulkheads

### 3.1 General

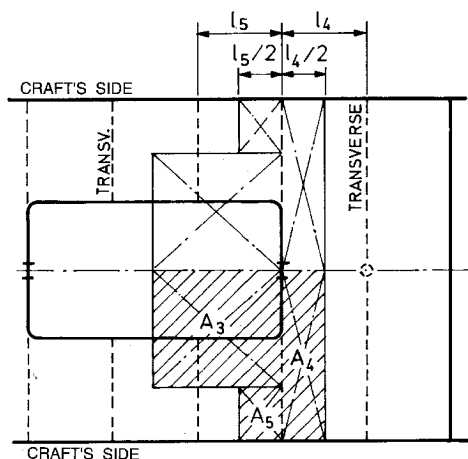
**3.1.1** Bulkheads supporting decks are to be regarded as pillars. Compressive loads are to be calculated based on supported deck area and deck design loading.

**3.1.2** Buckling strength of stiffeners are to be calculated as indicated in [Sec.10 \[5.1.1\]](#), assuming a plate flange equal to 40 x the plate thickness when calculating  $I_A$ ,  $A$  and  $i$ .

Local buckling strength of adjoining plate and torsional buckling strength of stiffeners are to be checked.



**Figure 1 Deck with transverse beams**



**Figure 2 Deck with longitudinals**

## SECTION 8 WELD CONNECTIONS

### 1 General

#### 1.1 Introduction

**1.1.1** In this section requirements for welding of aluminium alloys and various connection details are given.

**1.1.2** For general requirements for approval of welding of wrought aluminium alloys, see [SHIP Pt.2 Ch.4 Sec.5](#).

#### 1.2 Welding particulars

**1.2.1** Welding at ambient air temperature of  $-5^{\circ}\text{C}$  or below is only to take place after special agreement.

**1.2.2** The welding sequence is to be such that the parts may as far as possible contract freely in order to avoid cracks in already deposited runs of weld. Where a butt meets a seam, the welding of the seam is to be interrupted well clear of the junction and not be continued until the butt is completed. Welding of butt is to continue past the open seam and the weld be chipped out for the seam to be welded straight through.

**1.2.3** Welding procedures and welding consumables approved for the type of connection and parent material in question, are to be used. See "Register of Approved Manufacturers" and "Register of Type Approved Products".

### 2 Types of welded joints

#### 2.1 Butt joints

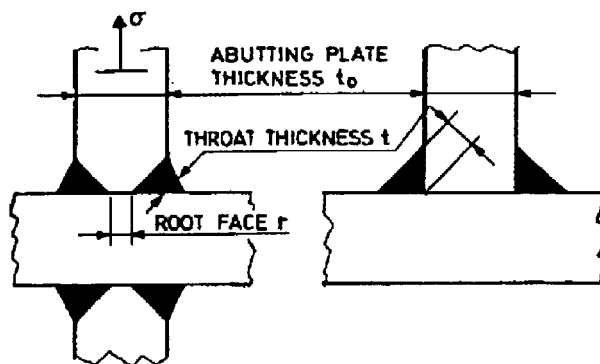
**2.1.1** For panels with plates of equal thickness, the joints are normally to be butt welded with prepared edges.

**2.1.2** For butt welded joints of plates with thickness difference exceeding 2 mm, the thicker plate is normally to be tapered. The taper is generally not to exceed 1:3.

**2.1.3** Welding against permanent or temporary backing is to be specially considered with respect to fatigue, non-destructive examination and any risk of crevice corrosion.

## 2.2 Tee or cross joints

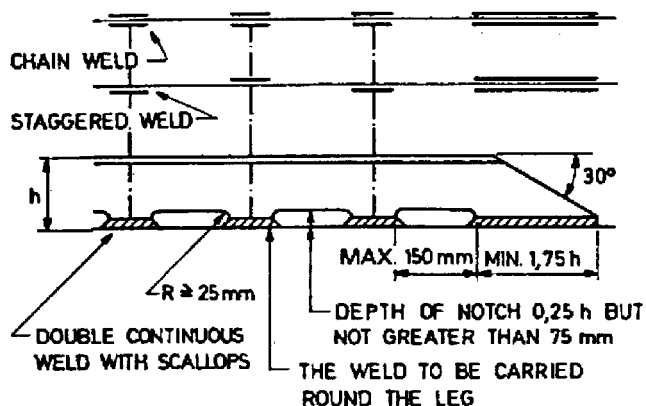
**2.2.1** The connection of girder and stiffener webs to plate panels, including plating abutting to other plate panels, is normally to be made by fillet welds as indicated in Figure 1.



**Figure 1 Tee or cross joints**

Where the connection is highly stressed, the edge of the abutting plate may have to be bevelled to give deep or full penetration welding. All welds on outer hull shell boundary as well as centre girder to keel plate shall be full penetration welding. Where the connection is moderately stressed, intermittent welds may be used. With reference to Figure 2, the various types of intermittent welds are as follows:

- chain weld
- staggered weld
- scallop weld (closed).



**Figure 2 Intermittent welds**

**2.2.2** Double continuous welds are required in the following connections irrespective of the stress level:

- oiltight and watertight connections
- connections in foundations and supporting structures for machinery
- all connections in way of the steering gear arrangement
- connections in rudders, except where access difficulties necessitate slot welds
- all connections in a region above the propeller extending a radius of minimum  $1.5 \times$  the propeller diameter
- connections at supports and ends of stiffeners, pillars, cross ties and girders
- centreline girder to keel plate
- all structures in ballast tanks and other tanks holding corrosive liquids.

### 3 Size of connections

#### 3.1 Fillet welds, general

**3.1.1** Unless otherwise stated, the requirements for throat thicknesses are given for double continuous fillet welds. It is assumed that the welding consumables used will give weld deposits with yield strength according to [SHIP Pt.2 Ch.2 Sec.10 \[1.9\]](#).

**3.1.2** The throat thickness of double continuous fillet weld is not to be less than:

$$t = 0.42 t_0 \text{ (mm)}$$

$t_0$  = thickness in mm of thinner of the plates.

The throat thickness is not to be less than 2 mm.

The throat thickness may have to be increased when considered necessary due to a high stress level.

**3.1.3** The throat thickness of intermittent welds is to be as required in [\[3.1.2\]](#) for double continuous welds provided the welded length is not less than:

- 80% of total length in the slamming area forward of amidships
- 60% of total length for connections in tanks and bottom aft of amidships
- 45% of total length for connections elsewhere.

$t_0$  = as given in [\[3.1.2\]](#).

Total length means total length of double continuous welds.

**3.1.4** Double continuous welds may be required in:

- slamming area
- engine room area
- adjacent to tanks.

#### 3.2 Fillet welds and penetration welds subject to high tensile stresses

**3.2.1** In structural parts where high tensile stresses ( $> 50 \text{ N/mm}^2$ ) act through an intermediate plate (see [Figure 1](#)) increased fillet welds or penetration welds are to be used. Examples of such structures are:

- transverse bulkhead connection to the double bottom
- structural elements in double bottoms below bulkheads
- transverse girders to longitudinal bulkheads.

**3.2.2** The throat thickness of double continuous weld is not to be less than:

$$t = 0.35 \left( \frac{\sigma}{55} + \frac{r}{t_0} - 1 \right) t_0 \text{ (mm)}$$

$\sigma$  = calculated maximum tensile stress in abutting plate in  $\text{N/mm}^2$   
 = minimum  $50 \text{ N/mm}^2$

$r$  = root face in mm  
 $t_0$  = thickness in mm of thinner of the plates.

### 3.3 End connections of girders, pillars and cross ties

**3.3.1** The weld connection area of bracket to adjoining girders or other structural parts is to be based on the calculated normal and shear stresses. Double continuous welding is to be used. Where high tensile stresses are expected, welding according to [3.2] is to be applied.

**3.3.2** The end connections of simple girders are to satisfy the requirements for section modulus given for the girder in question.

Where shear stresses in web plates exceed  $35 f_w \text{ N/mm}^2$ , double continuous boundary fillet welds are to have throat thickness not less than:

$$t = \frac{\tau t_0}{80 f_w} \text{ (mm)}$$

$\tau$  = calculated shear stress in  $\text{N/mm}^2$   
 $t_0$  = thickness of abutting plate.  
 $f_w$  = material factor for weld deposit  
 $= \sigma_{fw}/240$   
 $\sigma_{fw}$  = yield strength in  $\text{N/mm}^2$  of weld deposit.

**3.3.3** End connections of pillars and cross ties are to have a weld area not less than:

$$a = \frac{0.14Ap}{f_w} \text{ (cm}^2\text{)}$$

$A$  = load area in  $\text{m}^2$  for pillar or cross tie  
 $p$  = design pressure in  $\text{kN/m}^2$  as given in Ch.1  
 $f_w$  = as given in [3.3.2].

### 3.4 End connections of stiffeners

**3.4.1** Stiffeners may be connected to the web plate of girders in the following ways:

- welded directly to the web plate on one or both sides of the frame
- connected by single- or double-sided lugs
- with stiffener or bracket welded on top of frame
- a combination of the above mentioned connections.

In locations with great shear stresses in the web plate, a double-sided connection or a stiffening of the unconnected web plate edge is normally required. A double-sided connection may be taken into account when calculating the effective web area.

**3.4.2** The connection area at supports of stiffeners is normally not to be less than:

$$a_0 = \frac{c k (l - 0.5s) s p}{f_w} \text{ (cm}^2\text{)}$$

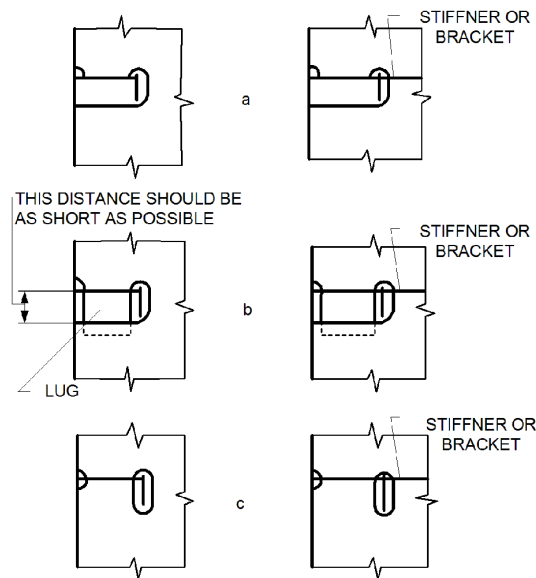
$c$  = factor as given in Table 1  
 $k$  = 0.125 for pressure acting on stiffener side  
       = 0.1 for pressure acting on opposite side  
 $l$  = span of stiffener in m  
 $s$  = spacing between stiffeners in m  
 $p$  = design pressure in kN/m<sup>2</sup> as given in Ch.1  
 $f_w$  = as given in [3.3.2].

**Table 1 c-factors**

Type of connection (see Figure 3)	Stiffener or bracket on top of stiffener		
	None	Single-sided	Double-sided
a	1.00	1.25	1.00
b	0.90	1.15	0.90
c	0.80	1.00	0.80

**3.4.3** Various standard types of connections are shown in Figure 3.

Other types of connection will be considered in each case.



**Figure 3 End connections**

**3.4.4** Connection lugs are to have a thickness not less than the web plate thickness.

**3.4.5** Lower ends of peak frames are to be connected to the floors by a weld area not less than:



$$a = \frac{0.105 / s p}{f_w} \text{ (cm}^2\text{)}$$

$l$ ,  $s$   $p$  and  $f_w$  = as given in [3.4.2].

**3.4.6** Bracketed end connections as mentioned in [3.4.7] and [3.4.8] are to have a weld area not less than:

$$a = \frac{kZ}{f_w h} \text{ (cm}^2\text{)}$$

$Z$  = section modulus of stiffener in  $\text{cm}^3$

$h$  = stiffener height in mm

$k$  = 24 for connections between supporting plates in double bottoms and transverse bottom frames or reversed frames

= 25 for connections between the lower end of main frames and brackets

= 15 for brackets fitted at lower end of tween deck frames, and for brackets on stiffeners

= 10 for brackets on tween deck frames carried through the deck and overlapping the underlying bracket

$f_w$  = as given in [3.3.2].

**3.4.7** Brackets between transverse deck beams and frames or bulkhead stiffeners are to have a weld area not less than:

$$a = 0.41 \sqrt{Z t_b} \text{ (cm}^2\text{)}$$

$t_b$  = thickness in mm of bracket

$Z$  = as defined in [3.4.6].

**3.4.8** The weld area of brackets to longitudinals is not to be less than the sectional area of the longitudinal. Brackets are to be connected to bulkhead by a double continuous weld.

## SECTION 9 DIRECT STRENGTH CALCULATIONS

### 1 General

#### 1.1 Introduction

**1.1.1** In the preceding sections the scantlings of the various primary and secondary hull structures (girder systems, stiffeners and plating) have been given explicitly, based on the design principles outlined in [Ch.1 Sec.2](#). In some cases direct strength or stress calculations have been referred to in the text. The background and assumptions for carrying out such calculations in addition to or as a substitute to the specific requirements are given in this section. Load conditions, allowable stresses and applicable calculation methods are specified.

#### 1.2 Application

**1.2.1** The application of direct stress analysis is governed by:

- Required as part of rule scantling determination.* In such cases where simplified formulations are not able to take into account special stress distributions, boundary conditions or structural arrangements with sufficient accuracy, direct stress analysis has been required in the rules.
- As alternative basis for the scantlings.* In some cases direct stress calculations may give reduced scantlings, especially when optimisation routines are incorporated.

### 2 Plating

#### 2.1 General

**2.1.1** Normally direct strength analysis of laterally loaded plating is not required as part of rule scantling estimation.

**2.1.2** Buckling control of plating subjected to large in-plane compressive stresses is specified in [Sec.4](#).

#### 2.2 Calculation procedure

**2.2.1** Laterally loaded local plate fields may be subject to direct stress analysis applying general 3-dimensional plate theory or finite element calculations. The calculations should take into account the boundary conditions of the plate field as well as membrane stresses developed during deflection of the plate.

#### 2.3 Allowable stresses

**2.3.1** When combining the calculated local bending stress with in-plane stresses the equivalent stress  $\sigma_e$  in the middle of a local plate field is not to exceed  $240 f_1 \text{ N/mm}^2$ . The local bending stress in the same point is in no case to exceed  $160 f_1 \text{ N/mm}^2$ .

$$\sigma_e = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \cdot \tau^2}$$

$\sigma_x$  = arithmetic sum of local bending stress and in-plane stresses in the x-direction

$\sigma_y$  = arithmetic sum of local bending stress and in-plane stresses in the y-direction

$\tau$  = shear stress in the xy-plane.

**2.3.2** The final thickness is not, however, to be less than the minimum thickness given in [Sec.5](#) for the structure in question.

## 3 Stiffeners

### 3.1 General

**3.1.1** Direct strength analysis of stiffeners may be requested in the following cases:

- stiffeners on supports with different deflection characteristics
- stiffeners subjected to large bending moments transferred from adjacent structures at supports.

**3.1.2** Buckling control of stiffeners subjected to large axial, compressive stresses is specified in [Sec.4](#).

### 3.2 Calculation procedure

**3.2.1** The calculations are to reflect the structural response of the 2- or 3-dimensional structure considered. Calculations based on elastic beam theory may normally be applied, with due attention to:

- boundary conditions
- shear area and moment of inertia variations
- effective flange
- effects of bending, shear and axial deformations
- influence of end brackets.

### 3.3 Loads

**3.3.1** The local lateral loads are to be taken as specified in [Ch.1](#) for the structure in question.

### 3.4 Allowable stresses

**3.4.1** The allowable stress level is given in [Table 1](#).

**Table 1 Allowable stress levels**

Nominal local bending stress	$\sigma = 160 f_1 \text{ N/mm}^2$
Combined local bending stress or girder stress or longitudinal stress	$\sigma = 220 f_1 \text{ N/mm}^2$
Nominal shear stress	$\tau = 90 f_1 \text{ N/mm}^2$

## 4 Primary structure elements

### 4.1 General

**4.1.1** For primary structure elements which are parts of a complex 2- or 3-dimensional structural system, a complete structural analysis may have to be carried out to demonstrate that the stresses are acceptable when the structure is loaded as described in [4.3].

**4.1.2** Calculations as mentioned in [4.1.1] may be requested to be carried out for:

- bottom structures
- side structures
- deck structures
- bulkhead structures
- transverse structures
- other structures when deemed necessary by the Society.

**4.1.3** In addition to the complex structures indicated above, direct strength calculations may also be performed on more simple girders in order to optimise scantlings.

### 4.2 Calculation methods

**4.2.1** Calculation methods or computer programs applied are to take into account the effects of bending, shear, axial and torsional deformations.

The calculations are to reflect the structural response of the 2- or 3-dimensional structure considered, with due attention to boundary conditions.

For systems consisting of slender girders, calculations based on beam theory (frame work analysis) may be applied, with due attention to:

- shear area variation
- moment of inertia variation
- effective flange.

**4.2.2** For deep girders, bulkhead panels, etc. where results obtained by applying the beam theory are unreliable, finite element analysis or equivalent methods are to be applied.

### 4.3 Design load conditions

**4.3.1** The calculations are to be based on loads at design level as given in Ch.1. For sea-going conditions realistic combinations of external and internal dynamic loads are to be considered.

The mass of deck structures may be neglected when less than 5% of the applied loads.

**4.3.2** For transverse web frame beam element analysis, the following combinations of load apply:

- sea pressure on all elements
- slamming pressure on bottom.

If twin hull, the following three conditions are to be added:

- slamming pressure on bottom from outside and sea pressure on hull outer side
- slamming pressure on bottom from inside and sea pressure on tunnel side and tunnel top
- slamming pressure on tunnel top and sea pressure on tunnel side and bottom from inside

For all load cases, deck load pressure from cargo, passengers, etc., is to be added.

## 4.4 Allowable stresses

**4.4.1** The equivalent stress is defined as:

$$\sigma_e = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \cdot \tau^2}$$

$\sigma_x$  = normal stress in x-direction

$\sigma_y$  = normal stress in y-direction

$\tau$  = shear stress in the xy-plane.

**4.4.2** The longitudinal combined stress taken as the sum of hull girder and longitudinal bottom, side or deck girder bending stresses, is normally not to exceed  $190 f_1 \text{ N/mm}^2$ .

**4.4.3** For girders in general, the following stresses are normally acceptable:

*Normal stress:*

$$\sigma = 160 f_1 \text{ N/mm}^2.$$

*Mean shear stress:*

$$\tau = 90 f_1 \text{ N/mm}^2 \text{ for girders with one plate flange}$$

$$\tau = 100 f_1 \text{ N/mm}^2 \text{ for girders with two plate flanges.}$$

*Equivalent stress:*

$$\sigma_e = 180 f_1 \text{ N/mm}^2.$$

## SECTION 10 BUCKLING CONTROL

### 1 General

#### 1.1 Definitions

##### 1.1.1 Symbols:

$t$	= thickness in mm of plating
$s$	= shortest side of plate panel in m
$l$	= longest side of plate panel in m
	= length in m of stiffener, pillar etc.
$E$	= modulus of elasticity of the material
	= $0.69 \cdot 10^5 \text{ N/mm}^2$ for aluminium
$\sigma_{el}$	= the ideal elastic (Euler) compressive buckling stress in $\text{N/mm}^2$
$\sigma_f$	= minimum upper yield stress of material in $\text{N/mm}^2$ . Usually base material properties are used, but critical or extensive weld zones may have to be taken into account
$\tau_{el}$	= the ideal elastic (Euler) shear buckling stress in $\text{N/mm}^2$
$\tau_f$	= minimum shear yield stress of material in $\text{N/mm}^2$
	= $\frac{\sigma_f}{\sqrt{3}}$
$\sigma_c$	= the critical compressive buckling stress in $\text{N/mm}^2$
$\tau_c$	= the critical shear stress in $\text{N/mm}^2$
$\tau_c$	= calculated actual compressive stress in $\text{N/mm}^2$
$\tau_a$	= calculated actual shear stress in $\text{N/mm}^2$
$\eta$	= stability (usage) factor = $\sigma_a/\sigma_c = \tau_a/\tau_c$
$Z_n$	= vertical distance in m from the baseline or deckline to the neutral axis of the hull girder, whichever is relevant
$Z_a$	= vertical distance in m from the baseline or deckline to the point in question below or above the neutral axis, respectively.

### 1.1.2 Relationships:

$$\sigma_c = \sigma_{el} \text{ when } \sigma_{el} < \frac{\sigma_f}{2}$$

$$= \sigma_f \left( 1 - \frac{\sigma_f}{4\sigma_{el}} \right) \text{ when } \sigma_{el} > \frac{\sigma_f}{2}$$

$$\tau_c = \tau_{el} \text{ when } \tau_{el} < \frac{\tau_f}{2}$$

$$= \tau_f \left( 1 - \frac{\tau_f}{4\tau_{el}} \right) \text{ when } \tau_{el} > \frac{\tau_f}{2}$$

#### Guidance note:

When the required  $\sigma_c$  or  $\tau_c$  is known, the necessary  $\sigma_{el}$  or  $\tau_{el}$  will follow from the above expressions of the Johnson-Ostenfeld relationship be

$$\sigma_{el} = \frac{\sigma_c}{K_{J-0}} \text{ and } \tau_{el} = \frac{\tau_c}{K_{J-0}}$$

$K_{J-0}$  from Figure 1 or from formula

$$K_{J-0} = 1 - \left( \frac{\sigma_c \text{ or } \tau_c}{0.5(\sigma_f \text{ or } \tau_f)} - 1 \right)^2$$

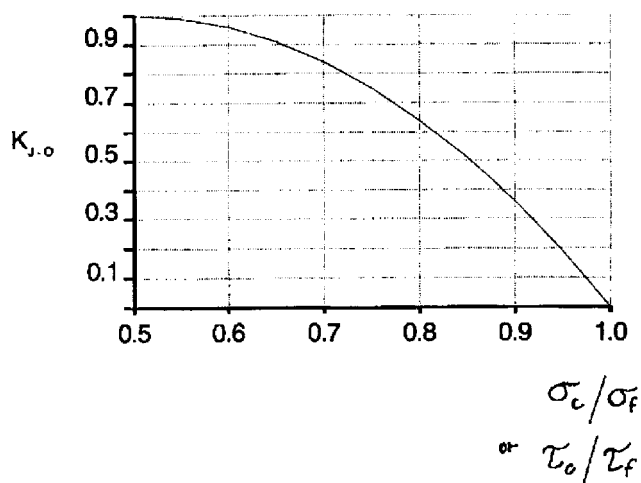


Figure 1

$$\text{For } \frac{\sigma_c}{\sigma_f} < 0.5, K_{J-1} = 1$$

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

## 2 Longitudinal buckling load

### 2.1 Longitudinal stresses

2.1.1 See Ch.1 Sec.4 [1.7].

## 3 Transverse buckling load

### 3.1 Transverse stresses

3.1.1 Transverse hull stresses in compression may occur from:

- transverse loads and moments in twin hull craft, see Sec.4 [5]
- supports of craft's side structure, see Sec.6.

## 4 Plating

### 4.1 Plate panel in uni-axial compression

4.1.1 The ideal elastic buckling stress may be taken as:

$$\sigma_{el} = 0.9 k E \left( \frac{t}{1000s} \right)^2 \text{ (N/mm}^2\text{)}$$

For plating with longitudinal stiffeners (in direction of compressive stress):

$$k = k_l = \frac{8.4}{\psi + 1.1} \text{ for } (0 \leq \psi \leq 1)$$

For plating with transverse stiffeners (perpendicular to compressive stress):

$$k = k_s = c \left[ 1 + \left( \frac{s}{l} \right)^2 \right]^2 \frac{2.1}{\psi + 1.1} \text{ for } (0 \leq \psi \leq 1)$$

- $c$  = 2.50 when stiffeners are hollow profiles with  $s/l < 0.5$  and the enclosed area of the hollow profile is larger than  $20 s \cdot t$   
 = 1.21 when stiffeners are angles or T-sections  
 = 1.10 when stiffeners are bulb flats  
 = 1.05 when stiffeners are flat bars.

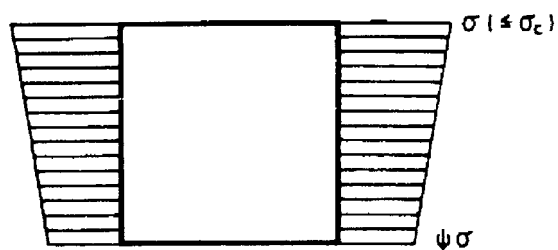
For double bottom panels the  $c$ -values may be multiplied by 1.1.



$\psi$  is the ratio between the smaller and the larger compressive stress assuming linear variation, see Figure 2.

The above correction factors are not valid for negative values of  $\psi$ .

The critical buckling stress is found from [1.1.2].



**Figure 2 Buckling stress correction factor**

**4.1.2** The critical buckling stress shall be related to the actual compressive stresses as follows:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

$\sigma_a$	=	calculated compressive stress in plate panels. With linearly varying stress across the plate panel, $\sigma_a$ shall be taken as the largest stress
$\eta$	=	0.9 for bottom and inner bottom plating in double bottoms
$\eta$	=	1.0 for deck, side, single bottom and longitudinal bulkhead plating
	=	1.0 for locally loaded plate panels where an extreme load level is applied
	=	$\eta_G$ for locally loaded plate panels where a normal load level is applied (e.g. plating acting as effective flange for girders)
$\eta_G$	=	$\frac{p_s + 0.5p_d}{p_s + p_d}$
$p_s$ and $p_d$	=	static and dynamic parts of p.

**Guidance note:**

The resulting thickness requirement (before elastic buckling) will be:

- with stiffeners in direction of compressive stress:

$$t = 2s \sqrt{\frac{\sigma_c}{K_{J-0}}} \quad (\text{mm})$$

$\sigma_c$  according to [4.1.2]

$K_{J-0}$  from Figure 1

- with stiffeners perpendicular to compressive stress:

$$t = 4 \frac{s}{1 + \left(\frac{s}{l}\right)^2} \sqrt{\frac{\sigma_c}{cK_{J-0}}} \quad (\text{mm})$$

c according to [4.1.1].

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

**4.1.3** For elastic buckling, see [7].

## 4.2 Plate panel in shear

**4.2.1** The ideal elastic buckling stress may be taken as:

$$\tau_{el} = 0.9k_t E \left( \frac{t}{1000s} \right)^2 \quad (\text{N/mm}^2)$$

$$k_t = 5.34 + 4 \left( \frac{s}{l} \right)^2$$

The critical shear buckling stress is found from [1.1.2].

**4.2.2** The critical shear stress shall be related to the actual shear stresses as follows:

$$\tau_c \geq \frac{\tau_a}{\eta}$$

$\eta$  = 0.90 for craft's side and longitudinal bulkhead subject to hull girder shear forces  
 = 0.95  $\eta_G$  for local panels in girder webs when nominal shear stresses are calculated ( $\tau_a = Q/A$ )  
 =  $\eta_G$  for local panels in girder webs when shear stresses are determined by finite element calculations or similar  
 $\eta_G$  = according to [4.1.2].

**Guidance note:**

The resulting thickness requirement will be:

$$t = 4s \sqrt{\frac{\tau_c}{k_t K_{J-0}}} \quad (\text{mm})$$

$\tau_c$  according to [4.2.2]

$K_{J-0}$  from Figure 1.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

### 4.3 Plate panel in bi-axial compression and shear

**4.3.1** For plate panels subject to bi-axial compression the interaction between the longitudinal and transverse buckling strength ratios is given by:

$$\frac{\sigma_{ax}}{\eta_x \sigma_{cx} q} - K \frac{\sigma_{ax} \sigma_{ay}}{\eta_x \eta_y \sigma_{cx} \sigma_{cy} q} + \left( \frac{\sigma_{ay}}{\eta_y \sigma_{cy} q} \right)^n \leq 1$$

$\sigma_{ax}$  = compressive stress in longitudinal direction (perpendicular to stiffener spacing  $s$ )  
 $\sigma_{cx}$  = critical buckling stress in longitudinal direction as calculated in [4.1]  
 $\sigma_{cy}$  = critical buckling stress in transverse direction as calculated in [4.1]

$\tau_a$  and  $\tau_c$  are as given in [4.2]

$\eta_x \eta_y$  = 1.0 for plate panels where the longitudinal stress  $\sigma_a$  (as given in Ch.1 Sec.4 [1.7]) or other extreme stress is incorporated and constitutes a major part in  $\sigma_{ax}$  or  $\sigma_{ay}$   
 = 0.95  $\eta_G$  other cases  
 $\eta_G$  = according to [4.1.2]  
 $K$  =  $c \cdot \beta^a$

$c$  and  $a$  are factors given in Table 1

$$\beta = 1000 \frac{s}{t} \sqrt{\frac{\sigma_f}{E}}$$

$n$  = factor given in Table 1

**Table 1 Factors for buckling strength**

	$c$	$a$	$n$
$1.0 < l/s < 1.5$	0.78	- 0.12	1.0
$1.5 \leq l/s < 8$	0.80	0.04	1.2

$$q = 1 - \left( \frac{\tau_a}{\eta_\tau \tau_c} \right)^2$$

$\eta_\tau$  =  $\eta$  as given in [4.2].

Only stress components acting simultaneously shall be inserted in the formula.

For plate panels in structures subject to longitudinal stresses, such stresses shall be directly combined with local stresses to the extent they are acting simultaneously and for relevant load conditions. Otherwise combinations based on statistics may be applied.

**Guidance note:**

For shear in combination with:

— *uni-axial compression*:

may be written:

$$\frac{\sigma_{ax}}{\sigma_{cx}} \text{ or } \frac{\sigma_{ay}}{\sigma_{cy}} \leq (\eta_x \text{ or } \eta_y) q$$

and with:

— *bi-axial compression, approximately*:

$$\frac{\sigma_{ax}}{\eta_x \sigma_{cx}} + 1.1 \frac{\sigma_{ay}}{\eta_y \sigma_{cy}} - \frac{0.8}{\eta_x \eta_y} \frac{\sigma_{ax}}{\sigma_{cx}} \frac{\sigma_{ay}}{\sigma_{cy}} \leq q$$

For bi-axial compression alone  $q = 1$ .

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

## 5 Stiffeners in direction of compression

### 5.1 Lateral buckling mode

**5.1.1** The ideal elastic lateral buckling stress may be taken as:

$$\sigma_{el} = 10 \frac{E}{\left(100 \frac{l}{i}\right)^2} \text{ (N/mm}^2\text{)}$$

$$i = \sqrt{\frac{I_A}{A}}$$

$I_A$  = moment of inertia in  $\text{cm}^4$  about the axis perpendicular to the expected direction of buckling  
 $A$  = cross-sectional area in  $\text{cm}^2$ .

When calculating  $I_A$  and  $A$ , a plate flange equal to 0.8 times the spacing is included for stiffeners.

The critical buckling stress is found from [1.1.2].

The formula given for  $\sigma_{el}$  is based on hinged ends and axial force only.

Continuous stiffeners supported by equally spaced girders are regarded as having hinged ends when considered for buckling.

In case of eccentric force, additional end moments or additional lateral pressure, the strength member shall be reinforced to withstand bending stresses.

**5.1.2** For longitudinals and other stiffeners in the direction of compressive stresses, the critical buckling stress calculated in [5.1.1] shall be related to the actual compressive stress as follows:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

$\sigma_a$  = calculated extreme compressive stress, or ordinary local load stress divided by  $\eta_G$  from [4.1]

$\eta$  = 0.85 for continuous stiffeners.

=  $1 - \eta_b$ , maximum 0.85 for single-span stiffeners

$\eta_b$  = (simultaneous bending moment at midspan)/bending moment capacity

**Guidance note:**

The resulting maximum allowable slenderness will be:

$$100 \frac{l}{i} = 830 \sqrt{\frac{K_{J-0}}{\sigma_c}}$$

$$\sigma_c = \frac{\sigma_a}{\eta}$$

$K_{J-0}$  from Figure 1.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

## 5.2 Torsional buckling mode

**5.2.1** For longitudinals and other stiffeners in the direction of compressive stresses, the ideal elastic buckling stress for the torsional mode may in general be calculated from formulae in DNVGL CG0128 *Buckling analysis*.

**5.2.2** The critical buckling stress as found from [5.2.1] and [1.1.2] shall not be less than:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

$\sigma_a$  = calculated extreme compressive stress, or ordinary local load stress divided by  $\eta_G$  from [4.1]

$\eta$  = 0.85 in general

= 0.8 when the adjacent plating is allowed to buckle in the elastic mode, according to [7].

**Guidance note:**

To avoid torsional buckling the height of flats should not exceed:

$$h_w = t_w \frac{140}{\sqrt{\frac{\sigma_c}{K_{J-0}}}} \quad (\text{mm})$$

$t_w$  = thickness of web in mm

$$\sigma_c = \frac{\sigma_a}{\eta}$$

$K_{J-0}$  from Figure 1.

For flanged profiles,  $1 < h_w/b_f < 3$

Minimum flange breadth may be taken as:

For symmetrical flanges:

$$b_f = 5l \sqrt{\frac{\sigma_c}{K_{J-0}}} \quad (\text{mm})$$

For unsymmetrical flanges:

$$b_f = 3.5l \sqrt{\frac{\sigma_c}{K_{J-0}}} \quad (\text{mm})$$

$$\sigma_c = \frac{\sigma_a}{\eta}$$

$K_{J-0}$  = according to Figure 1

$h_w$  = height of web in mm.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

## 5.3 Web and flange buckling

**5.3.1** The  $\sigma_{el}$  -value required for the web buckling mode may be taken as:

$$\sigma_{el} = 3.8 E \left( \frac{t_w}{h_w} \right)^2 \quad (N/mm^2)$$

$t_w, h_w$  = web thickness and height in mm.

**5.3.2** The ideal elastic buckling stress of flange of angle and tee stiffeners may be calculated from the following formula:

$$\sigma_{el} = 0.38 E \left( \frac{t_f}{b_f} \right)^2 \quad (N/mm^2)$$

$t_f$  = flange thickness in mm

$b_f$  = flange width in mm for angles, half the flange width for T-sections.

**5.3.3** The critical buckling stress  $\sigma_c$  found from [1.1.2] shall not be less than as given in [5.2.2].

- Web thickness, see plating with stiffener in direction of compression stress, [4.1.3].
- Flange width from web:

$$b_f < t_f \frac{140}{\sqrt{\frac{\sigma_c}{K_{J-0}}}} \quad (\text{mm})$$

$\sigma_c$  = according to [5.2.2]

$K_{J-0}$  = according to Figure 1



## 6 Stiffeners perpendicular to direction of compression

### 6.1 Moment of inertia of stiffeners

**6.1.1** For stiffeners supporting plating subject to compressive stresses perpendicular to the stiffener direction the moment of inertia of the stiffener section (including effective plate flange) shall not be less than:

$$I = \frac{0.81 \sigma_a \sigma_{el} l^4 s}{t} \quad (cm^4)$$

$l$  = span in m of stiffener  
 $s$  = spacing in m of stiffeners  
 $t$  = plate thickness in mm

$$\sigma_{el} = \frac{\sigma_c}{K_{J-0}}$$

$$\sigma_c = \frac{\sigma_a}{0.85}$$

$\sigma_a$  = calculated extreme compressive stress, or ordinary local load stress divided by  $\eta_G$  from [4.1]  
 $K_{J-0}$  = according to Figure 1.

## 7 Elastic buckling of stiffened panels

### 7.1 Elastic buckling as a design basis

**7.1.1** Elastic buckling may be accepted for plating between stiffeners when:

- plating  $\sigma_{el} = \sigma_f/2$  i.e.  $\sigma_{el} = \sigma_c$
- $\eta \sigma_c$  of stiffener in direction of compression  $> \eta \sigma_{el}$  of plating.  
 $\eta \sigma_c$  from [5] and [1.1.2]. To be multiplied by  $\eta_G$  for ordinary local load.  
 $\eta \sigma_{el}$  from [4] and [1.1.2]
- there are no functional requirements limiting the deflections
- extreme loads are used in the calculations.

**Guidance note:**

For the torsional buckling mode of flats may be taken

$$\sigma_{el} = 0.385 E \left( \frac{t_w}{h_w} \right)^2 \quad (N/mm^2)$$

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

## 7.2 Allowable compression

**7.2.1** The allowable compressive force in the panel may be increased from:

$$P_A = 0.1 \eta_p \sigma_{el} (A_p + A_s) \text{ (kN)}$$

to:

$$P_A = 0.1 \eta_p \sigma_{el} (A_p + A_s) +$$

$$0.1(\eta_s \sigma_c - \eta_p \sigma_{el}) \left( \frac{b_e}{b} A_p + A_s \right) \text{ (kN)}$$

$\eta_p, \eta_s$  =  $\eta$  for plating and stiffener from [4] and [5].  $\eta_s$  to be multiplied by  $\eta_G$  for ordinary local load  
 $\sigma_{el}, \sigma_c$  = for plating and stiffener, respectively, from [4] and [5]. Ordinary effective flange shall be used for stiffeners

$A_p, A_s$  = area of plating and stiffener in cm<sup>2</sup>  
 $b_e/b$  = fraction of  $A_p$  participating in the post-buckling stress increase

$$= \frac{\sigma_u - \sigma_{el}}{\sigma_f - \sigma_{el}}$$

$\sigma_u$  = ultimate average stress of plating

$$= \sigma_{el} \left[ 1 + 0.375 \left( \frac{\sigma_f}{\sigma_{el}} - 2 \right) \right]$$

**7.2.2** For transversely stiffened plating (compressive stress perpendicular to longest side  $l$  of plate panel) is

$$\sigma_u = \sigma_{el} \left[ 1 + c \left( \frac{\sigma_f}{\sigma_{el}} - 2 \right) \right]$$

$$c = \frac{0.75}{\frac{l}{s} + 1}$$

$$A_s = 0$$

resulting in:

$$P_A = 0.1 \eta_p \sigma_u A_p \text{ (kN)}.$$

**7.2.3**  $\sigma_u$  may be substituted for  $\sigma_{el}$  when calculating uniaxial compression and shear in [4.3].

## 8 Primary structure elements

### 8.1 Axial load buckling

**8.1.1** For lateral, torsional, web and flange buckling, see [5], Stiffeners in direction of compression.

### 8.2 Primary structure elements perpendicular to direction of compression

**8.2.1** For transverse primary structure elements supporting longitudinals or stiffeners subject to axial compression stresses, the ideal elastic buckling stress may be taken as:

$$\sigma_{el} = 1.38 \frac{\pi^2}{S^2(t + t_a)} \sqrt{\frac{I_a I_b}{sl}}$$

$S$  = span of girder in m

$l$  = distance between girders in m

$s$  = spacing of stiffeners in m

$I_a$  = moment of inertia of stiffener in cm<sup>4</sup>

$I_b$  = moment of inertia of transverse girder in cm<sup>4</sup>

$t$  = plate thickness in mm

$t_a$  = equivalent plate thickness of stiffener area in mm  
= (stiffener area)/(stiffener spacing)

The critical buckling stress  $\sigma_c$  is found from [1.1.2].

**8.2.2** The critical buckling stress found from [8.2.1] and [1.1.2] shall not be less than:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

$\sigma_a$  = calculated compressive stress

$\eta$  = 0.75.

### 8.3 Buckling of effective flange

**8.3.1** Plating acting as effective flange for girders which support crossing stiffeners is to have a satisfactory buckling strength.

**8.3.2** Compressive stresses arising in the plating due to local loading of girders shall be less than  $\eta_G$  x the critical buckling strength, see [8.3.3]. When calculating the compressive stress the section modulus of the girder may be based on a plate flange breadth equal to the distance between girders (100% effective flange).

$\eta_G$ : see [4.1].

**8.3.3** The critical buckling strength is given in [4.1.1] and [1.1.2], when  $l$  = span of stiffener or distance from girder to eventual buckling stiffener parallel to the girder.

**8.3.4** Elastic buckling of deck plating may be accepted after special consideration.

Reference is made to [7].

The additional  $P_A$ , and the corresponding additional moment capacity, will, however, refer to a girder section with effective width of deck plating =  $b_e$ .

## 8.4 Shear buckling of web

**8.4.1** See [4.2], for constant shear force over  $l$ .

### Guidance note:

For variable shear force over  $l$  of panel, a reduced  $l$  may be considered in formula.

---e-n-d---of---g-u-i-d-a-n-c-e---n-o-t-e---

## **DNV GL**

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