RULES FOR CLASSIFICATION

High speed and light craft

Edition December 2015

Part 3 Structures, equipment

Chapter 2 Hull structural design, steel

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DNV GL AS

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.

Any comments may be sent by e-mail to *rules@dnvgl.com*

CHANGES – CURRENT

This is a new document.

The rules enter into force 1 July 2016.

CONTENTS

Changes – current ... **3**

Section 1 Structural principle ... **10**

1 General ... **10**

1.1 Applicability ... 10

1.2 The scantling reduction ... 10

1.3 Documentation ... 10

1.4 Certification ... 11

2 Bottom structures ... **11**

2.1 Longitudinal stiffeners ... 11

2.2 Longitudinal girders ... 11

2.3 Engine room ... 11

2.4 Double bottom ... 12

2.5 Bilge keel ... 12

2.6 Bottom transverses and girders ... 12

2.7 Docking ... 12

3 Side structure ... **12**

3.1 Stiffeners ... 12

3.2 Side transverses and stringers ... 12

3.3 Cross ties ... 13

4 Deck structure ... **13**

4.1 Plating ... 13

4.2 Stiffeners ... 13

4.3 Bulwarks ... 14

5 Flat cross structure ... **14**

5.1 General ... 14

5.2 Stiffeners ... 14

6 Bulkhead structures ... **14**

6.1 Transverse bulkheads ... 14

6.2 Corrugated bulkheads ... 14

6.3 Supporting bulkheads ... 15

7 Superstructures and deckhouses ... **16**

7.1 Definitions ... 16

7.2 End bulkheads of superstructures and deckhouses, and exposed sides in deckhouses ... 16

8 Structural design in general ... **16**

8.1 Craft arrangement...16
8.2 Continuity and transition of local members...17
9 Some common local design rules.. 17
9.1 Definition of span...17
9.2 End connection of stiffeners...17
9.3 End connections of girders.. 18
9.4 Effective flange of girders..19
9.5 Effective web of girders.. 19
9.6 Stiffening of girders..20
9.7 Girder tripping brackets... 21
9.8 Reinforcement at knuckles...23
10 Support of equipment and outfitting details..................................... 23
10.1 Heavy equipment, appendages etc...23
10.2 Welding of outfitting details to hull.. 23
11 Structural aspects not covered by the rules..................................... 24
11.1 Deflections..24
11.2 Local vibrations.. 24

Section 2 Materials and material protection..25
1 General... 25
1.1 Introduction...25
2 Hull structural steel...25
2.1 General.. 25
2.2 Material designations and material factors.................................... 25
2.3 Material factor, f..25
2.4 Basic requirements... 26
2.5 Material at cross-joints.. 26
3 Alternative Structural Materials...26
3.1 Aluminium.. 26
3.2 Connections between steel and aluminium......................................26
3.3 Stainless steel...27
4 Corrosion protection... 28
4.1 General.. 28
4.2 Application of coating.. 28
4.3 Provisions to avoid galvanic corrosion... 29
4.4 Specification of cathodic protection...29
4.5 Interactions with other electrical systems.. 29

Section 3 Manufacturing, inspection, testing..30

1 General.. 30
1.1 Basic requirements.. 30
2 Inspection.. 30
2.1 Non-destructive testing.. 30
2.2 Magnetic particle testing.. 30
2.3 Radiographic testing... 30
2.4 Ultrasonic examination.. 30
3 Extent of examination... 31
3.1 General... 31
4 Acceptance Criteria for NDT.. 31
4.1 Acceptance criteria.. 31
5 Testing... 31
5.1 Tanks.. 31
5.2 Closing appliances... 31

Section 4 Hull girder strength.. 32
1 General.. 32
1.1 Introduction... 32
2 Vertical bending strength.. 32
2.1 Hull section modulus requirement.................................. 32
2.2 Effective section modulus... 32
2.3 Hydrofoil on foils.. 33
2.4 Longitudinal structural continuity.................................. 33
2.5 Openings... 34
3 Shear strength... 34
3.1 Cases to be investigated... 34
4 Cases to be investigated... 34
4.1 Inertia induced loads.. 34
5 Transverse strength of twin hull craft............................ 35
5.1 Transverse strength.. 35
5.2 Allowable stresses.. 35

Section 5 Steel plating and stiffeners................................ 37
1 General.. 37
1.1 Introduction... 37
1.2 Definitions... 37
1.3 Allowable stresses.. 37
2 Plating... 39
2.1 Minimum thickness... 39

2.2 Formulae..40
2.3 Bottom and bilge plating..40
2.4 Sea inlets and other openings...40
3 Stiffeners... 40
3.1 Formulae and evaluations...40
3.2 Bulkhead stiffeners other than longitudinals...42
3.3 Machinery casings.. 43
3.4 Weather deck hatch covers. Shell doors.. 43

Section 6 Steel webframes and girder systems...44
1 General.. 44
1.1 Introduction..44
1.2 Definitions... 44
1.3 Allowable stress.. 44
2 Web frames and girders.. 45
2.1 General... 45
2.2 Strength requirements... 45
2.3 Minimum thicknesses and geometrical ratios..48
2.4 Weather deck hatch covers. Shell doors.. 48
2.5 Doors in watertight bulkheads.. 49

Section 7 Steel pillars and pillar bulkheads..50
1 General.. 50
1.1 Introduction..50
1.2 Definitions... 50
2 Pillars...50
2.1 Arrangement of pillars.. 50
2.2 Pillar scantlings... 50
2.3 Pillars in tanks...53
3 Supporting bulkheads...53
3.1 General... 53

Section 8 Welding and weld connections.. 54
1 General.. 54
1.1 Introduction..54
1.2 Welding particulars.. 54
2 Types of welded joints.. 54
2.1 Butt joints.. 54
2.2 Lap joints and slot welds... 54
2.3 Tee or cross joints..55

3 Load based weld scantlings....57
3.1 Joints of abutting webs or plates....57
3.2 Steel and weld support of stiffeners to girders....59
3.3 Steel and weld end connections of longitudinals....61
3.4 Weld end connections of stiffeners in general....61
3.5 End connections of girders, pillars and cross ties....63
4 Minimum weld scantlings....64
4.1 Minimum fillet weld....64

Section 9 Direct strength calculations....65
1 General....65
1.1 Introduction....65
1.2 Application....65
2 Plating....65
2.1 General....65
3 Stiffeners....65
3.1 General....65
3.2 Calculation procedure....66
3.3 Loads....66
3.4 Allowable stresses....66
4 Girders....67
4.1 General....67
4.2 Calculation methods....67
4.3 Design load conditions....67
4.4 Allowable stresses....67
4.5 Allowable deflections....69

Section 10 Buckling control....70
1 General....70
1.1 Definitions....70
2 Longitudinal buckling load....71
2.1 Longitudinal stresses....71
3 Transverse buckling load....72
3.1 Transverse stresses....72
4 Plating....72
4.1 Plate panel in uni-axial compression....72
4.2 Plate panel in shear....74
4.3 Plate panel in bi-axial compression and shear....74
5 Stiffeners in direction of compression....76

5.1 Lateral buckling mode....76
5.2 Torsional buckling mode....77
5.3 Web and flange buckling....78
6 Stiffeners Perpendicular to Direction of Compression....79
6.1 Moment of inertia of stiffeners....79
7 Elastic buckling of stiffened panels....79
7.1 Elastic buckling as a design basis....79
7.2 Allowable compression....79
8 Girders....81
8.1 Axial load buckling....81
8.2 Girders perpendicular to direction of compression....81
8.3 Buckling of effective flange....81
8.4 Shear buckling of web....82

SECTION 1 STRUCTURAL PRINCIPLE

1 General

1.1 Applicability

1.1.1 This chapter is applicable for all craft built in steel. It is also applicable to parts constructed of steel on vessels built in another material than steel.

1.2 The scantling reduction

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

— thorough corrosion protection of steel, carried out under indoor conditions
— a certain stiffener spacing reduction ratio s/s_r

s = chosen spacing in mm
s_r = basic spacing
= $2 \cdot (240 + L)$ mm in general, including tank bulkheads
= 760 mm for other bulkheads

— longitudinal framing in bottom and strength deck
— extended global longitudinal and local buckling control
— a sea and weather service restriction.

1.3 Documentation

1.3.1 The builder shall submit the documentation required by Table 1. The documentation will be reviewed by the Society as a part of the class contract.

Table 1 Documentation requirements

Object	*Documentation type*	*Additional description*	*Info*
Structural materials, steel	M010 - Material specifications, metals	Including welding consumables	FI
Coating	M040 – Coating specification		AP
Sacrificial anodes	M050 – Cathodic specification, calculation and drawing		AP
Structural fabrication	H131 – Non-destructive testing (NDT) plan		AP
Welding	H140 – Welding tables		AP
Vibration	Z243 – Assessment report	Evaluation of structural response to vibrations caused by impulses from engine and propeller blades. See Sec.1 [11.2.1]	FI
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 Pt.1 Ch.3 Sec.2.
For a full definition of the documentation types, see Pt.1 Ch.3 Sec.3.

1.4 Certification

1.4.1 For products that shall be installed on board, the builder shall request the manufacturers to order certification as described inTable 2

Table 2 Certification requirements

Object	*Certificate type*	*Issued by*	*Certification standard**	*Additional description*
Materials for hull structure	MC	The Society		Rolled steel
Materials for special parts	MC	The Society		Material for forgings, castings and other materials for special parts and equipment. As stated in connection with the rule requirements for each individual part
Deck composition	TA	The Society		They are to be of an elastic, non-hygroscopic material. Deck compositions for application in cargo areas are to be suitably reinforced
* Unless otherwise specified the certification standard is the rules.				

For general certification requirements, see SHIP Pt.1 Ch.3 Sec.4
For a definition of the certification types, see SHIP Pt.1 Ch.1 Sec.4 and SHIP Pt.1 Ch.3 Sec.5

2 Bottom structures

2.1 Longitudinal stiffeners

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

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

2.1.3 Longitudinal stiffeners in slamming area shall have a shear connection to transverse members.

2.2 Longitudinal girders

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

2.2.2 Manholes or other openings should not be positioned at ends of girders without due consideration being taken of shear loading.

2.3 Engine room

2.3.1 In way of thrust bearings additional strengthening is to be provided.

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

2.3.3 Engine holding down bolts are to be arranged as near as practical to floors and longitudinal girders.

2.4 Double bottom

2.4.1 In case a double bottom is fitted, the following and [2.4.2] and [2.4.3] apply. 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 in general. Centre of lightening holes to be, as close as practicable, to the neutral axes of elements in question. 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.

2.4.2 In transversely stiffened double bottoms, the bottom girders are to be stiffened at every frame.

2.4.3 The bottom girders are to be satisfactory stiffened against buckling.

2.5 Bilge keel

2.5.1 The bilge keel and the flat bar to which it is attached, is not to terminate abruptly. Ends are to be tapered, and internal stiffening is to be provided. Butts in the bilge keel and the flat bar are to be well clear of each other and of butts in the shell plating.

The bilge keel and flat bar are to be of the same material strength as the bilge strake to which they are attached.

2.6 Bottom transverses and girders

2.6.1 For rise of floor > 45° the case with unsymmetrical side force from sea pressure have to be investigated, and the efficiency of the support of floors shall be examined.

2.7 Docking

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

2.7.2 Structure in way of docking blocks is to be evaluated for the given docking forces.

3 Side structure

3.1 Stiffeners

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

Guidance note:

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

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

3.1.2 Where the craft's sides are longitudinally stiffened and depending upon the area under consideration, the continuity of the longitudinals is to be as required for the bottom and deck longitudinals, respectively.

3.2 Side transverses and stringers

3.2.1 For weather deck stringer plate along wide hatch opening, the following may have to be investigated above ordinary side stringer requirements:

— combined deflection of stringer and hatch coaming at weather tightening level, when subjected to side and deck sea pressure
— continuity of inner flange at hatch ends.

3.3 Cross ties

3.3.1 Cross ties may be regarded as effective for side vertical when:

— the cross tie extends from side to side
— the cross tie is supported by other structure which may be considered rigid when subject to the maximum expected axial loads in the cross tie
— the load condition may be considered symmetrical with respect to the cross tie.

3.3.2 Cross ties and panting beam scantlings are to be determined as for deck pillars, where the deck load is to be substituted by the load on the supported side. Bending stress and suspended bending deflection of slender cross ties may have be taken into account.

4 Deck structure

4.1 Plating

4.1.1 If the end bulkhead of a long superstructure is located within 0.5 L amidships, the stringer plate is to be increased in thickness for a length of 3 m on each side of the superstructure end bulkhead. The increase in thickness is to be 20 %.

4.1.2 If hatch opening corners of streamlined shape are not adopted, the thickness of deck plates in strength deck at hatch corners is to be increased by 25%.

The longitudinal extension of the thicker plating is not to be less than 1.5 R and not more than 3 R on both sides of the hatch end. The transverse extension outside line of hatches is to be at least 2 R.

R = corner radius.

4.1.3 The seam between the thicker plating at the hatch corner and the thinner plating in the deck area between the hatches is to be located at least 100 mm inside the point at which the curvature of the hatch corner terminates.

4.2 Stiffeners

4.2.1 Decks taking part of the longitudinal strength are normally to be longitudinally stiffened. Where main stresses are in the transverse direction, the deck may be transversely stiffened.

4.2.2 Longitudinals should preferably be continuous through transverse members. If they are to be cut at transverse members, e.g. at watertight bulkheads, brackets connecting the ends of the longitudinals are to be fitted.

4.3 Bulwarks

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

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

5 Flat cross structure

5.1 General

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

5.1.2 The cross structure should be arranged with the possibility for inspection of all parts of the structure.

5.2 Stiffeners

5.2.1 Flat cross structure taking part of the longitudinal strength are normally to be longitudinally stiffened. Where main stresses are in the transverse direction, the flat cross structure may be transversely stiffened.

5.2.2 Where the cross structure is transversely stiffened, transverse bulkheads and frames are to be continuous through longitudinal bulkheads.

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.

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 The lower and upper ends of corrugated bulkheads and those boundaries of vertically corrugated bulkheads connected to ship sides and other bulkheads are to have plane parts of sufficient width to support the adjoining structures.

6.2.3 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 in general.
= s_2 or s_3 for plate thickness calculation when 90 degrees corrugations.

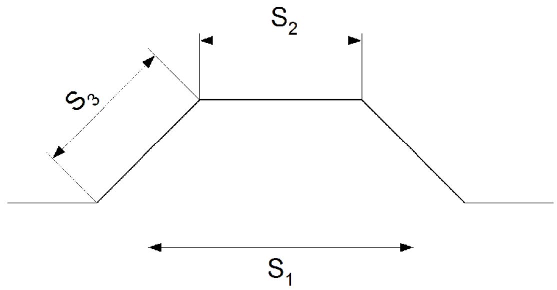

Figure 1 Corrugated bulkhead

Section modulus and thickness formulae as for plane bulkheads may be used.

6.2.4 Unless the buckling strength is proved satisfactory by direct stress calculation the following additional requirements apply to corrugated bulkheads (where t and s_2 and s_3 are taken in same units):

$$t = \frac{s_2}{50} \text{ when } \frac{s_2}{s_3} = 0,5$$

$$t = \frac{s_2}{70} \text{ when } \frac{s_2}{s_3} \geq 1,0$$

Intermediate values are obtained by linear interpolation. For a corrugated bulkhead with a section modulus greater than required, the required thickness may be multiplied by:

$$\sqrt{\frac{Z_{rule}}{Z_{actual}}}$$

Z_{rule} = required section modulus. May be taken at section in question based upon a direct stress calculation

6.3 Supporting bulkheads

6.3.1 Bulkheads supporting decks are to be regarded as pillars. The compressive loads and buckling strength are to be calculated as given in Sec.7.

7 Superstructures and deckhouses

7.1 Definitions

Table 3

Term	Definition
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
superstructure	is defined as a decked structure on the freeboard deck, extending from side to side of the craft or with the side plating not inboard of the shell plating more than 4 % of the breadth (B)

7.2 End bulkheads of superstructures and deckhouses, and exposed sides in deckhouses

7.2.1 For deckhouse stiffeners the scantlings need not be greater than required for between deck frames with equivalent end connections.

7.2.2 Front stiffeners are to be connected to deck at both ends with a connection area not less than:

$$a = 0.07\, l \cdot s \cdot p \text{ [cm}^2\text{]}$$

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

7.2.3 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.

7.2.4 For hull girder strength in way of rows of openings, see Sec.4.

8 Structural design in general

8.1 Craft arrangement

8.1.1 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/pillar rings in the engine room
- twin hull connections
- superstructures and deckhouses:
- direct support
- transitions
- deck equipment support
- multi-deck pillars in line, as practicable

— external attachments, inboard connections.

8.2 Continuity and transition of local members

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

8.2.2 Structural continuity is to be maintained at the junction of primary supporting members of unequal stiffness by fitting well rounded brackets. Brackets are not to be attached to unsupported plating. Brackets are to extend to the nearest stiffener, or local plating reinforcement is to be provided at the toe of the bracket.

8.2.3 Gradual taper or soft transition is especially important in high speed steel craft, to avoid:

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

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

8.2.5 Web frames are to be continuous around the cross section i.e. floors, side webs and deck beams are to be aligned and connected. Intermediate floors may be used.

8.2.6 In superstructures and deckhouses aft, the front bulkhead is to be in line with a transverse bulkhead in the hull below or be supported by a combination of partial transverse bulkheads, girders 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 located above bulkheads and/or deep girder frames in the hull structure and are to be in line in the various tiers of accommodation. Where such structural arrangements in line are not possible, there is to be other effective support.

8.2.7 Where practicable, deck pillars are to be located in line with pillars above or below. Pillars are to be supported by rigid hull structures.

8.2.8 Below decks and platforms, strong transverses or longitudinal girders are to be fitted between verticals and pillars, so that rigid continuous structures are formed.

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 in Figure 2. It is assumed that brackets are effectively supported by the adjacent structure.

9.2 End connection of stiffeners

9.2.1 Normally all types of stiffeners (longitudinals, beams, frames, bulkhead stiffeners) are to be connected at their ends. In special cases, however, sniped ends may be allowed.

9.2.2 Bracketless end connections may be applied for longitudinals and other stiffeners running continuously through girders (web frames, transverses, stringers, bulkheads etc.), provided sufficient connection area is arranged for.

9.2.3 Stiffeners with sniped ends may be allowed where dynamic loads are small and where vibrations are considered to be of small importance, provided the thickness of plating supported by the stiffener is not less than:

$$t = 1.25\sqrt{\frac{(l - 0.5s)s \cdot p}{f_1}} \text{ [mm]}$$

l = stiffener span in m
s = stiffener spacing in m
p = pressure on stiffener in kN/m^2.

9.3 End connections of girders

9.3.1 Normally, ends of single girders, or connections between girders forming ring systems, are to be provided with brackets. Brackets are generally to form a radius or be well rounded at their toes. The free edges of the brackets are to be stiffened in case free edge length is in excess of 50t, where t is the bracket thickness.

Bracketless connections may be applied provided adequate support of the adjoining faceplates is arranged for.

The brackets shown in Figure 3 ALT. II and ALT. III are normally considered better than the basic design. Other brackets may be accepted after special consideration.

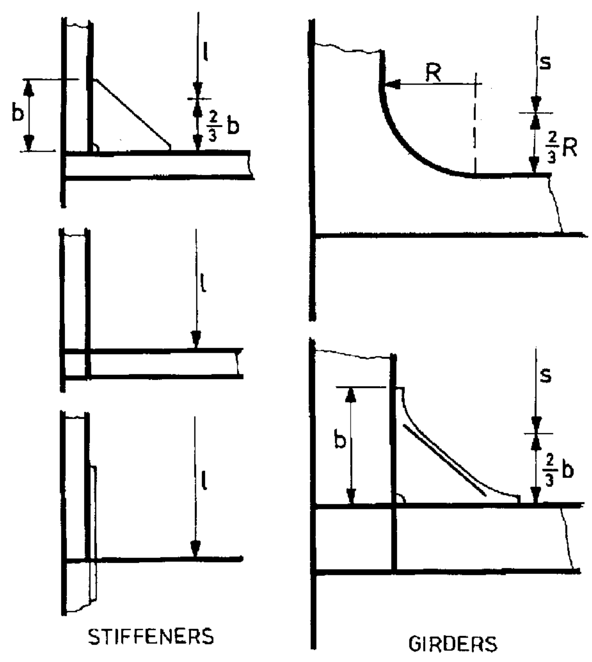

Figure 2 Span points

9.4 Effective flange of girders

9.4.1 The section modulus of the girder is to be taken in accordance with particulars as given in the following. Structural modelling in connection with direct stress analysis is to be based on the same particulars when applicable. Note that such structural modelling will not reflect the stress distribution at local flange cut-outs 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".

9.4.2 The effective plate flange area is defined as the cross-sectional area of plating within the effective flange width. Continuous stiffeners within the effective flange may be included. The effective flange width b_e is determined by the following formula:

$$b_e = C \cdot b \quad [m]$$

C = as given in Table 4 for various numbers of evenly spaced point loads (r) on the span
b = the sum of the plate flange width on each side of girder, normally taken to be half the distance from the nearest girder or bulkhead
a = the distance between points of zero bending moments
= S for simply supported girders
= 0.6 S for girders fixed at both ends
r = number of point loads.

Table 4 Values of C

a/b	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*≥7*
C (r > 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 < 3)	0.00	0.22	0.40	0.52	0.65	0.73	0.78	0.80

9.4.3 For plate flanges having corrugations parallel to the girder, the effective width is as given in [9.4.2]. If the corrugations are perpendicular to the direction of the girder, the effective width is not to be taken greater than 10 % of the value derived from [9.4.2].

9.5 Effective web of girders

9.5.1 The web area of a girder is to be taken in accordance with particulars as given in [9.5.2] and [9.5.3]. Structural modelling in connection with direct stress analysis is to be based on the same particulars when applicable.

9.5.2 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.

9.5.3 For ordinary girder cross sections the effective web area is to be taken as:

$$A_w = 0.01\, h_n \cdot t_w [cm^2]$$

h_n = net girder height in mm after deduction of cut-outs in the cross section considered

= $h_{nl} + h_{n2}$.

If an opening is located at a distance less than $h_w/3$ from the cross section considered, h_n is to be taken as the smaller of the net height and the net distance through the opening. See Figure 4.

9.6 Stiffening of girders

9.6.1 The web plate of transverse vertical girders is to be stiffened where:

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

t_w = web thickness in mm
h_w = web height in mm

with stiffeners of maximum spacing:

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

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

Elsewhere stiffeners are required where:

$$h_w > 140\ t_w\ (\text{mm})$$

with stiffeners of maximum spacing:

$$s = 140\ t_w\ (\text{mm})$$

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

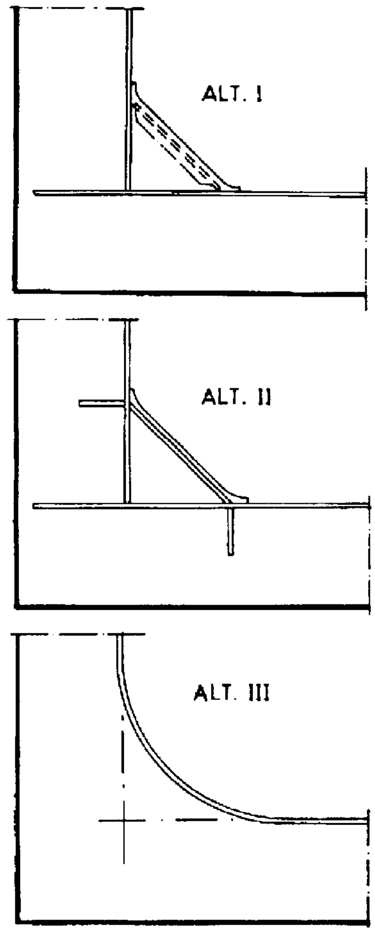

Figure 3 Bracket design

9.6.2 The web plate is to be especially stiffened at openings when the mean shear stress exceeds 60 f_1 N/mm^2.

9.7 Girder tripping brackets

9.7.1 The spacing value, S_T, of tripping brackets is normally not to exceed the values given in Table 5 which is valid for girders with symmetrical face plates. For others, the spacing will be especially considered.

Table 5 Spacing between tripping brackets

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

Tripping brackets are furthermore to be fitted near the toe bracket, near rounded corner of girder frames and in way of cross ties.

9.7.2 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.

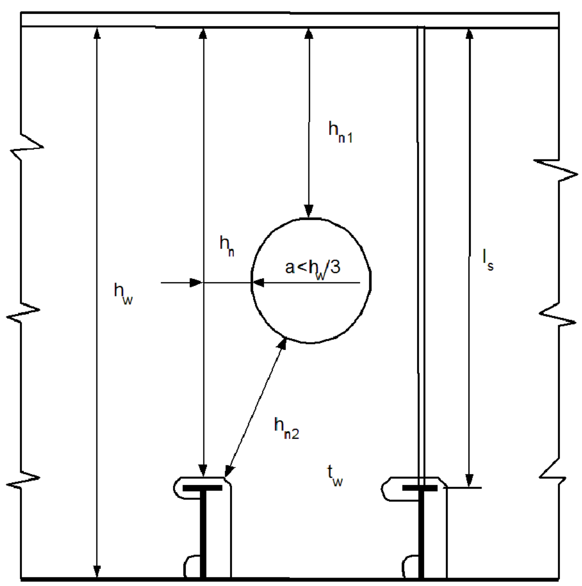

Figure 4 Effective web area in way of opening

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

$$0.06\ t_t\ [m]$$

thickness in mm of tripping brackets.

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

$$10\ l_t\ [\mathrm{cm}^2]$$

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.

9.7.4 Girders with unsymmetrical face plates are to have tripping brackets spaced not more than 10 times the width of face plate, maximum 1.5 metres.

9.8 Reinforcement at knuckles

9.8.1 Whenever a knuckle in a main member (shell, longitudinal bulkhead, etc.) is arranged, it is important to have some form of stiffening fitted at the knuckle to transmit the transverse force.

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 systems until the forces are safely carried to the craft's side or bulkheads taking into account the hull stresses that already exist.

10.1.2 Doublers should be avoided normal to a tensile force.

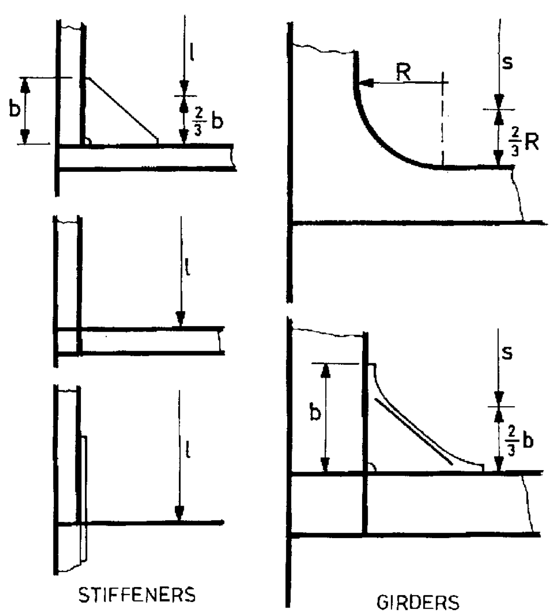

Figure 5 Span points

10.2 Welding of outfitting details to hull

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 is avoided as far as 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 Equipment details such as clips for piping, support of ladders, valves, anodes etc. are to be kept clear of the toe of brackets, edges of openings and other areas with high stresses.

Connections to the top flange of girders and stiffeners are to be avoided, if not well smoothened. Preferably, supports for out-fittings are to be welded to the stiffener web.

10.2.3 All materials welded to the hull shell structure are to be of ship quality steel, or equivalent, preferably with the same strength group as the hull structure the item is welded to.

11 Structural aspects not covered by the rules

11.1 Deflections

11.1.1 Rule requirements to minimum moment of inertia or maximum deflection under load are limited to structures in way of hatches and doors and some other special cases.

11.1.2 Deflection problems in general are left for the designer’s consideration.

11.2 Local vibrations

11.2.1 The evaluation of structural response to vibrations caused by impulses from engine and propeller blades are not covered by classification, but the builder is to provide relevant documentation.

Guidance note:

IMO HSC Code:

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

1) impair the integrity of structure during the anticipated service life of the craft or the service life agreed with the Administration;
2) hinder normal functioning of machinery and equipment; and
3) 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 Introduction

1.1.1 In this section requirements regarding the application of various structural materials as well as protection are given.

2 Hull structural steel

2.1 General

2.1.1 Where the rules for material grade in this section are dependent on plate thickness, the requirements are based on the thickness as built.

2.2 Material designations and material factors

2.2.1 Steel material grades and mechanical properties

Full details for requirements to material are given in SHIP Pt.2.

Steel having a specified minimum yield stress of 235 N/mm^{2}is regarded as normal strength hull structural steel. Steel having a specified minimum yield stress 235 < R_{eH}≤ 390 N/mm^2 is regarded as high strength hull structural steel. Steel having ReH > 390 N/mm^2 is regarded as extra high strength structural steel. In the following, material grades of hull structural steels are referred to as follows:

1) A, B, D, E and F denote normal strength steel grades.
2) AH, DH, EH and FH denote high strength and extra high strength steel grades, where 'H' indicates the material strength.

Normal strength is denoted 'NS' and high strength steel and extra high steel are denoted 'HT'.

Table 1 gives specified yield stress and tensile strength for rolled steels generally used in construction of ships.

Table 1 Mechanical properties of hull steels

Steel grades for plates with $t_{as\ built}$ ≤ 150 mm	*Specified minimum yield stress R_{eH} in N/mm^2*	*Specified tensile yield stress R_{eH} in N/mm^2*
A-B-D-E	235	400 - 520
A32-D32-E32-F32	315	440 - 570
A36-D36-E36-F36	355	490 - 630
A40-D40-E40-F40	390	510 - 660
A47-D47-E47-F47	460	570 - 720

2.2.2 Extra high tensile strength steel

The application of extra high strength steel with R_{eH} greater than 460 N/mm^2, will be considered on a case-by- case basis.

2.3 Material factor, f

Unless otherwise specified, the material factor, f, of normal and higher strength steel for hull girder strength and scantling purposes is to be taken as defined in Table 2.

For intermediate values of R_{eH}, f is obtained by linear interpolation.

Table 2 Material factor, f

Specified minimum yield stress R_{eH} in N/mm^2	*f*
235	1.00
315	1.28
355	1.39
390	1.49
460	1.92

2.4 Basic requirements

2.4.1 For a thickness more than 15 mm special consideration will be made with respect to material grade, according to SHIP Pt.3 Ch.3 Sec.1 Table 10.

2.5 Material at cross-joints

2.5.1 In important structural cross-joints where high tensile stresses are acting perpendicular to the plane of the plate, special consideration will be given to the ability of the plate material to resist lamellar tearing. For a special test, see Pt.2 Ch.2 Sec.1.

3 Alternative Structural Materials

3.1 Aluminium

3.1.1 Aluminium structures are to be designed and built according to Pt.3 Ch.3.

3.1.2 In designing a combined steel and aluminium structure, the difference in modulus of elasticity and coefficient of expansion must be taken into account.

3.2 Connections between steel and aluminium

3.2.1 If there is risk of galvanic corrosion, a non-hygroscopic insulation material is to be applied between steel and aluminium.

3.2.2 Aluminium plating connected to a steel boundary bar is as far as possible to be arranged on the side exposed to moisture.

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

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

For superstructures and deckhouses, the spacing is normally not to exceed 4 times the bolt diameter.

3.2.5 In case of rolled bi-metallic connections, high tensile forces normal to the bi-metallic contact surface should be avoided.

3.2.6 For earthing of aluminium superstructures and deckhouses to steel craft, see Pt.4 Ch.8.

3.3 Stainless steel

3.3.1 For clad steel and solid stainless steel due attention is to be given to the reduction of strength of stainless steel with increasing temperature. For austenitic stainless steel and steel with clad layer of austenitic stainless steel the material factor f_1 included in the various formulae for scantlings and in expressions giving allowable stresses is given in [3.3.2] and [3.3.3].

3.3.2 For austenitic stainless steel the material factor f_1 can be taken as:

$$f_1 = \left[\left(3{,}9 + \frac{t-20}{650}\right)\sigma_f - 4{,}15(t-20) + 220\right]10^{-3}$$

σ_f = yield stress in N/mm^2 at 0.2 % offset and temperature + 20 °C ($\sigma_{0,2}$).
t = cargo temperature in °C.

For end connections of corrugations, girders and stiffeners the factor is due to fatigue not to be taken greater than:

$$f_1 = 1.21 - 3.2\,(t - 20)\,10^{-3}$$

3.3.3 For clad steel the material factor f_1 can be taken as:

$$f_1 = \frac{1{,}67\sigma_f - 1{,}37\,t}{1000} - 41{,}5\sigma_{fb}^{-0{,}7} + 1{,}6$$

σ_f = yield stress in N/mm^2 at 0.2 % °C ($\sigma_{0,2}$)
σ_{fb} = yield strength in N/mm^2 of base material
t = cargo temperature in °C

f_1 is in no case to be taken greater than that given for the base material in [2.2.3]. The calculated factor may be used for the total plate thickness.

3.3.4 For ferritic-austenitic stainless steel the material factor will be especially considered in each case.

Guidance note:

For ferritic-austenitic stainless steels with yield stress 460 N/mm^2, the following material factor will normally be accepted:

f_1 = 1.6 at + 20°C

= 1.36 at + 85°C

For end connection of corrugations, girders and stiffeners the factor should due to fatigue not be taken greater than:

f_1 = 1.39 at + 20°C

= 1.18 at + 85°C

For intermediate temperatures linear interpolation may be applied for the f_1 factor.

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4 Corrosion protection

4.1 General

4.1.1 All steel surfaces except in tanks for oil for the craft's use are to be protected against corrosion by paint of suitable composition or other effective coating. Inner bottom and decks for dry cargoes will be especially considered.

4.1.2 In way of other materials (e.g. propellers), provisions are to be made to avoid galvanic corrosion.

4.2 Application of coating

4.2.1 The minimum cleanliness standard of steel for coating application is normally blast cleaning to Sa 2,5 according to SIS 055900, near-white according to SSPC-SP10, or an equivalent standard.

4.2.2 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 *Registers of approved manufacturers and type approved products*.

4.2.3 Coating systems are to be compatible with any previously applied shop primer. Proper cleaning of any primer or intermediate coating which has been exposed to the yard atmosphere for some time is necessary before application of the next coat.

4.2.4 The requirement for dry conditions during all essential steps of blast cleaning and coating applications is normally that:

— the steel surfaces are to be minimum 3°C above the dew point.
— the air humidity is at a maximum of 85%.

4.3 Provisions to avoid galvanic corrosion

4.3.1 Acceptable provisions are either one of or a combination of:

— coating of water/moisture exposed surfaces (mandatory according to [4.1.1])
— electrical insulation of different metals from each other
— cathodic protection.

Guidance note:

Full electrical insulation of e.g. the propeller from the hull might be difficult. Electrical contact between the propeller and the hull may be established when the propeller is idle.

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4.3.2 External cathodic protection of steel hulls in addition to the coating can be obtained with aluminium or zink sacrificial anodes or impressed current.

4.3.3 If impressed current systems are applied, precautions are to be taken to avoid overprotection by means of anode screen and overprotection alarm.

4.4 Specification of cathodic protection

Guidance note:

The current density demand will vary dependent on the speed of the hull, the speed of the propeller, etc.

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4.4.2 For documentation of instrumentation and automation, including computer based control and monitoring, see RU SHIP Pt.4 Ch.9 Sec.1.

4.4.3 The designed service life of cathodic protection systems is normally to be at least 5 years.

4.4.4 An acceptable criterion of efficient cathodic protection is that it is found successful at annual survey, i.e., that no corrosion has occurred.

Potential measurements may be required when considered necessary. The protective potential for steel hull surfaces in clean sea water is – 800 mV versus the Ag/AgCl reference electrode. The limit for overprotection is –1050 mV at the same conditions.

4.5 Interactions with other electrical systems

4.5.1 Stray DC currents may impose rapid electrolytic corrosion damages to hulls and are to be avoided.

Due consideration should be made to the above when utilizing onshore electrical current connection.

Guidance note:

Other stray DC current sources may be railways, cranes, cables, improperly grounded welding machines, etc.

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SECTION 3 MANUFACTURING, INSPECTION, TESTING

1 General

1.1 Basic requirements

1.1.1 Welding of important structures, machinery installations and equipment are to be carried out by qualified welders using approved welding procedures and welding consumables, see SHIP Pt.2 Ch.4.

1.1.2 For welding ambient temperature and welding details, see Sec.8.

1.1.3 Shot blasting, priming and coating is to be carried out under indoor conditions. For coating specification and documentation, see Sec.1.

2 Inspection

2.1 Non-destructive testing

2.1.1 Welds are to be subjected to visual survey and inspection, as fabrication proceeds. NDT is to be performed according to established procedures.

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

2.2 Magnetic particle testing

2.2.1 Magnetic particle testing shall be carried out as specified in the approved procedures.

2.3 Radiographic testing

2.3.1 Radiographic testing shall 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 shall be free from imperfections due to develop processing.

2.4 Ultrasonic examination

2.4.1 Ultrasonic testing shall be carried out as specified in the approved procedures. Ultrasonic examination procedures shall 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 records shall include the imperfection position, the echo height, the dimensions (length), and 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 subjected to 100% visual examination. In addition to the visual examination at least 2% to 5% of the total welded length is to be tested by magnetic particle examination and/or radiographic examination. For highly stressed areas the extent of examination may be increased.

3.1.2 If defects are detected, then the extent of the examination shall be increased to the satisfaction of the surveyor.

4 Acceptance Criteria for NDT

4.1 Acceptance criteria

4.1.1 All welds shall show evidence of good workmanship. The quality shall normally comply with ISO 5817 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 All tanks are, unless otherwise agreed, to be tested with a water head equal to the maximum pressure to which the compartment may be exposed. The water head is no case to be less than to top of air pipe or to a level h_0 above the top of 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 Watertight and weathertight, 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 kN/mm^2 at the nozzle. The nozzle should be held at a distance of maximum 1.5 m from the item under test.

Alternative methods of tightness testing may be considered.

5.2.3 All watertight/weathertight 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 as mentioned in the introduction to Ch.1 Sec.4.

1.1.3 For structurally complicated craft (e.g. multi-hull types) a complete 3-dimensional global analysis of the transverse strength, in combination with longitudinal stresses, shall be carried out.

1.1.4 Buckling strength in bottom and deck shall be verified for all craft. For this purpose formulae for estimate of section modulus to deck and bottom based on bottom and deck cross sectional areas have been given in Ch.1 Sec.4 [1.7].

2 Vertical bending strength

2.1 Hull section modulus requirement

2.1.1 The section modulus is calculated as follows:

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

M = the longitudinal midship bending moment in kNm from Ch.1 Sec.4.
σ = f_1 N/mm^2 in general.

When σ is taken greater than 175 N/mm^2, the bottom structure shall be assessed with respect to fatigue.

Guidance note:

Simultaneous end impacts over a hollow are considered less frequent, and giving lower moments than the crest landing. Simultaneous end impacts 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 When calculating the moment of inertia and section modulus of the midship section, the effective sectional area of continuous longitudinal strength members is in general to be taken as the net area after deduction of any 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 is assumed to have longitudinal extensions as shown by the shaded areas in Figure 1, i.e., inside tangents at an angle of 30 ° to each other. Example for transverse section III:

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

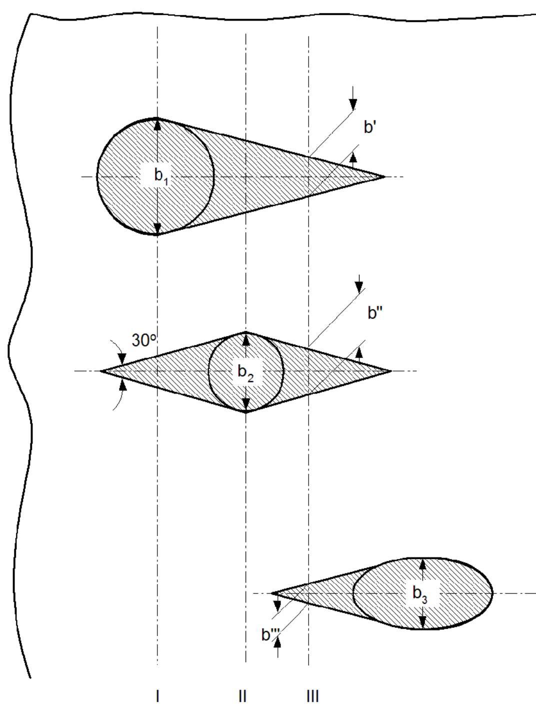

Figure 1 Effect of openings

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

2.3 Hydrofoil on foils

2.3.1 For hydrofoils the sections in way of the foils shall be considered, in addition to the calculations for the midship section.

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 shall 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 shall be fitted.

Guidance note:

Height to length ratio of the transition brackets shall be 1: 4 or better.

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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 shall be avoided as far as practicable. Any necessary openings in the bilge plate shall be kept clear of a bilge keel.

2.5.2 Openings in strength deck are as far as practicable to be located well clear of 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 shall be situated as near to the craft's centreline as practicable.

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

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

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 SHIP Pt.3 Ch.3 Sec.6 [6.3].

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

2.5.6 Studs for securing small hatch covers shall be fastened to the top of a coaming or a ring of suitable thickness welded 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 especially considered.

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

3.1.3 For the cases in [3.1.1] and [3.1.2] and for other locations with doubtful shear area, the allowable shear stress may be taken as:

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

4 Cases to be investigated

4.1 Inertia induced loads

4.1.1 Transversely framed parts of the forebody shall be checked for the axial inertia forces given in Pt.3 Ch.1 Sec.4 [1.7] as follows:

$$F_L = \Delta\ a_l\ [kN]$$

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

$$0{,}4\ g \text{ for } \frac{V}{\sqrt{L}} \geq 5$$

$$0{,}2\ g \text{ for } \frac{V}{\sqrt{L}} \leq 3$$

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

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

4.1.2 Bottom structure in way of thrust bearings may need to be checked for the increased thrust when the craft 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 shall be performed to investigate the structural consequence when subjected to the collision load as given in the International Code of Safety for High-Speed Craft, 4.3.3.

Guidance note:

Inertia forces from 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 shall 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 the net area with effective flange after deduction of openings.

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

5.2 Allowable stresses

5.2.1 The equivalent stress is defined as:

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

σ_x = total normal stress in x-direction
σ_y = total normal stress in y-direction
τ = 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: $\sigma = 160\ f_1$ (N/mm^2)
— Mean shear stress: $\tau = 90\ f_1$ (N/mm^2)
— Equivalent stress: $\sigma_e = 180\ f_1$ (N/mm^2)

SECTION 5 STEEL PLATING AND STIFFENERS

1 General

1.1 Introduction

1.1.1 In this section the general requirements for plate thicknesses and local strength of stiffeners in single skin panels are given.

1.1.2 For buckling control, see Sec.10.

1.2 Definitions

1.2.1 Symbols:

L, B, D, T, C_B, see Ch.1 Sec.1.

t	=	rule thickness in mm of plating
Z	=	rule section modulus in cm^3 of stiffeners
s	=	stiffener spacing in m, measured along the plating
		for corrugations, see Sec.1 [4]
		for wash bulkhead section modulus calculations s may be reduced according to size and location of openings
s_r	=	basic stiffener spacing
	=	2 (240 + L) (mm) in general
	=	760 mm for watertight bulkheads, cargo holds, bulkheads and superstructure and deckhouse bulkheads
l	=	stiffener span in m, measured along the topflange of the member. For definition of span point, see Sec.1 [6.1]. For curved stiffeners l may be taken as the cord length
σ	=	nominal allowable bending stress in N/mm^2. due to lateral pressure
p and p_{sl}	=	design pressure in kN/m^2 as given in Ch.1 Sec.3. To be calculated at load point as defined in Ch.1 Sec.3 [1]
Z_A	=	midship section modulus in cm^3 as built at deck or bottom, respectively
Z_R	=	rule midship section modulus in cm^3.

1.3 Allowable stresses

1.3.1 Maximum allowable bending stresses in plates and stiffeners are to be according to Table 1.

Table 1 Allowable bending stresses (Continued)

Item	*Plate*		*Stiffener*	
	Within 0.4 L	*Within 0.1 L from AF/FP*	*Within 0.4 L*	*Within 0.1 L from AP/FP*
	(N/mm^2)			
Bottom, slamming loads	160 f_1		150 f_1	
Bottom, sea load:	120 f_1	160 f_1		160 f_1

Item	*Plate*		*Stiffener*	
	Within 0.4 L	*Within 0.1 L from AF/FP*	*Within 0.4 L*	*Within 0.1 L from AP/FP*
	(N/mm^2)			
- longitudinals, $Z_A = Z_R$ [1)]			95 f_1	
- longitudinals, $Z_A \geq 2\ Z_R$ [1)]			160 f_1	
- transverse beams			160 f_1	
Side, slamming load	160 f_1		160 f_1	
Side, sea load:				
Longitudinal stiffening		180 f_1		160 f_1
- at neutral axis [2)]	180 f_1			
- at deck or bottom [2)]	120 f_1			
- 0.25 D above and below neutral axis [2)]			160 f_1	
Transverse stiffening,		160 f_1	160 f_1	
- at neutral axis [2)]	160 f_1			
- at deck or bottom [2)]	120 f_1			
Deck:				
Longitudinal stiffening	120 f_1	180 f_1		160 f_1
- $Z_A = Z_R$ [1)]			95 f_1	
- $Z_A \geq 2\ Z_R$ [1)]			160 f_1	
Transverse stiffening	120 f_1	160 f_1	160 f_1	
Flat cross structure longitudinal bulkhead:	160 f_1		150 f_1	
Longitudinal stiffening		160 f_1		
- at neutral axis [2)]	160 f_1			
- at deck or bottom [2)]	120 f_1			
Transverse stiffening		160 f_1	160 f_1	
- at neutral axis [2)]	140 f_1			
- at deck or bottom [2)]	120 f_1			
Transverse tank bulkhead	160 f_1		160 f_1	
Collision bulkhead	160 f_1		160 f_1	
Watertight bulkhead	220 f_1		220 f_1	
Watertight doors	135 f_1			
Superstructure/deckhouse, side/front	160 f_1		160 f_1	
Superstructure/deckhouse deck			160 f_1	

Item	Plate		Stiffener	
	Within 0.4 L	Within 0.1 L from AF/FP	Within 0.4 L	Within 0.1 L from AP/FP
	(N/mm^2)			
Shell doors			$135\ f_1$	
1) For $Z_R < Z_A < 2\ Z_R$ σ-values may be varied linearly. 2) Between specified regions σ-values may be varied linearly.				

2 Plating

2.1 Minimum thickness

2.1.1 The thickness of the structures is in general not to be less than:

$$t = (t_0 + kL)\frac{s}{s_r}(mm)$$

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
Shell plating:	Keel [1)]	7.0	0.05
	Bottom, bilge, side, sea inlets and other openings [2)]	5.0	0.04
Strength deck	Weather and cargo decks	4.5	0.025
	Accommodation deck	4.5	0.025
Plating of decks below strength deck	Cargo deck	4.0	0.02
	Accommodation deck	4.0	0.02
Plating of decks above strength deck	Weather exposed parts of first tier superstructure decks and deckhouse tops	4.0	0.02
	Accommodation	4.0	0.02
Bulkhead plating	Tank bulkheads and watertight bulkheads	5.0	0.025
	First tier of superstructure ends and exposed sides	5.0	0.01
Other structures	Structure not mentioned above	2.5	
1) The thickness of the keel plate is in no case to be less than that of the adjacent bottom plate. 2) The thickness of the bilge plate is not to be less than that of the adjacent bottom and side plates whichever is the greater.			

2.2 Formulae

2.2.1 The thickness requirement corresponding to lateral pressure or impact is given by:

$$t = \frac{15{,}8\, s \sqrt{p \text{ or } p_{sl}}}{\sqrt{\sigma}} \quad \text{(mm)}$$

σ as given in Table 1.

2.2.2 The following extended formula for thickness of plating exposed to lateral pressure may be used when relevant:

$$t = \frac{15{,}8\, k_a k_r s \sqrt{p \text{ or } p_{sl}}}{\sqrt{\sigma}} \quad \text{(mm)}$$

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 = (1− 0.5 s/r)
= correction factor for curved plates
r = radius of curvature in mm.

2.3 Bottom and bilge plating

2.3.1 Plating in way of rudder bearings, shaft brackets etc. may have to be increased.

2.4 Sea inlets and other openings

2.4.1 Location, see Sec.4 [2].

2.4.2 Sea inlet boxes are to have scantlings of plating and stiffeners as required for boundaries of tanks, but based on bottom shell sea pressure and half the surplus of the slamming pressure above the sea pressure.

2.4.3 For minor sea connections, see Pt.4 Ch.6 Sec.4.

3 Stiffeners

3.1 Formulae and evaluations

3.1.1 The section modulus requirement corresponding to lateral pressure or impact is given by:

$$z = \frac{ml^2 s(p \text{ or } p_{sl})}{\sigma} \quad (cm^3)$$

p or p_{sl} from Ch.1 Sec.2

l = span of the member in m
s = spacing in m
σ = nominal allowable stress due to lateral pressure, see Table 1
m = bending moment factor depending on the degree of end constrains and type of loading, see also Sec.6 Table 3.

The m-values are normally to be as given in Table 3.

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

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

Table 3 Values of m

Item	*m*
Continuous longitudinal members	85
Non-continuous longitudinal members	100
Transverse members	100
Vertical members, ends fixed	100
Vertical members, simply supported	135
Bottom	85
Bottom, transverse members	100
Sides, longitudinal members	85
Sides, vertical members	100
Decks, longitudinal members	85
Decks, transverse members	100
Watertight bulkhead stiffeners, fixed ends	65
Watertight bulkhead stiffeners, fixed one end (lower)	85
Watertight bulkhead stiffeners, fixed one end (upper)	75
Watertight bulkhead stiffeners, simply supported ends	125
Watertight bulkhead horizontal stiffeners, fixed ends	85
Watertight bulkhead horizontal stiffeners, simply supported ends	125
Tank bulkheads, fixed ends	100
Tank bulkheads, simply supported ends	135

Item	m
Deckhouse stiffeners	100
Casing stiffeners	100
Weather deck hatch covers	125
Shell doors	125
Doors in watertight bulkheads	125

3.1.2 The formula given in [3.1.1] is to be regarded as the requirement about an axis parallel to the plating. As an approximation, the requirement to 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:

$$1 / \cos \alpha$$

α = angle between the stiffener web plane and the plane perpendicular to the plating

For α-values less than 15° 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 The geometric properties of stiffeners (section modulus Z and in some cases moment of inertia I) may be calculated directly from the given dimensions in connection with the effective plate flange.

Effective plate flange may normally be taken equal to the stiffener spacing.

Z and I may also be obtained from published tables and curves.

Equal angles should be avoided for full bending due to reduced effective free flange by torsional stresses, and tripping effects.

3.1.5 The thickness of web and flange is not to be less than:

t_{web} for flats	= 1/15 x flat depth.
t_{web} for other sections	= 1/50 x web depth, provided net shear area ≥ 0.075 $l$sp
t_{flange}	= 1/15 x flange width from web.

3.2 Bulkhead stiffeners other than longitudinals

3.2.1 The end attachment of the stiffeners is to comply with the following requirements:

For tank, cargo hold and collision bulkheads: Bracket to be fitted at both ends according to Sec.1 [9.2].

For transverse watertight bulkheads, brackets are normally to be fitted at both ends. Brackets may be omitted, however, on the condition that the distance from top of the bulkhead to the lower end of the span is less than 6 s.

3.2.2 For cargo hold centre line partial bulkheads, which are not pillar bulkheads, see Sec.7, the following apply:

Section modulus requirement for stiffeners:

$$Z = 2\, l^2\, s \ [\mathrm{cm}^3]$$

The distance between stiffeners is not to be greater than 2 frame spacings.

3.3 Machinery casings

3.3.1 The section modulus of stiffeners is not to be less than:

$$Z = 3\, l^2\, s \ [\mathrm{cm}^3]$$

l = length of stiffeners in m, minimum 2.5 m.

3.3.2 Casings supporting one or more decks above are to be adequately strengthened, see Sec.7.

3.4 Weather deck hatch covers. Shell doors

3.4.1 In addition to the section modulus requirement, according to [3.1], the moment of inertia is not to be less than:

$$I = 1.7\, Z\, l \ [\mathrm{cm}^4].$$

SECTION 6 STEEL WEBFRAMES AND GIRDER SYSTEMS

1 General

1.1 Introduction

1.1.1 In this section the general requirements for simple girders in single skin structures are given. Procedures for the calculations of complex girder systems are given in Sec.9.

1.2 Definitions

1.2.1 Symbols

L, B, D, T, C_B, see Ch.1 Sec.1.

Z	=	rule section modulus in cm^3 of stiffeners and girders
s	=	stiffener spacing in m, measured along the plating
l	=	stiffener span in m, measured along the top flange of the member. For definition of span point, see Sec.1 [6.1]. For curved stiffeners l may be taken as the cord length
S	=	girder span in m. For definition of span point, see Sec.1 [6.1]
b	=	breadth of load area in m. b may be determined by Table 1
σ	=	nominal allowable bending stress in N/mm^2 due to lateral pressure
p and p_{sl}	=	design pressure in kN/m^2 as given in Ch.1 Sec.3. To be calculated at load point as defined in Ch.1 Sec.3 [1]
τ	=	nominal allowable shear stress in N/mm^2
P	=	design axial force in kN
A_W	=	rule web area in cm^2
A	=	rule cross sectional area in cm^2
t_w	=	web thickness in mm
h_w	=	web height in mm
b_f	=	flange breadth in mm

Table 1 Breadth of load area

For ordinary girders	b = 0.5 (l_1 + l_2.) (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) (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 if the hatchway
For hatch end beams	b = 0.4 b_3 (m) b_3 = distance in m between hatch and end beam and nearest deep transverse girder or transverse bulkhead

1.3 Allowable stress

1.3.1 Maximum allowable bending stresses and shear stresses in web frames and girders are to be according to Table 2.

Table 2 Allowable stress

	Web frames and girders	
	Bending stress *(N/mm²)*	*Shear stress* *(N/mm²)*
Longitudinal girders	Sec.5 Table 1	90 f_1
Hatch covers and shell door girders	135 f_1	80 f_1
Girders for watertight doors	200 f_1	
Other girders	160 f_1	90 f_1
Watertight bulkheads[1)]	220 f_1	120 f_1
1) For flooding loads		

2 Web frames and girders

2.1 General

2.1.1 The requirements for section modulus and web area given in [2.2] 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 especially 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.

2.2 Strength requirements

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

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

σ = according to Table 2
m = bending moment factor. m-values in accordance with [2.2.3] may be applied.

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

$$A_w = \frac{10\,(k_s S\, b\, p - a\, r)}{\tau} \quad (cm^2)$$

k_s = shear force factor

k_s-values in accordance with [2.2.3] 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
τ = according to Table 2

The a-value is in no case to be taken greater than:

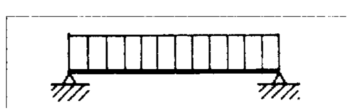
$$(n + 1) / 4$$

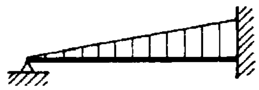
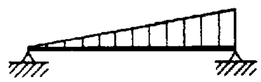
n = number of supported stiffeners on the girder span.

The web area at the middle of the span is not to be less than 0.5 A_W.

2.2.3 The m - and k_s- values referred to in [2.2.1] and [2.2.2] may be calculated according to general beam theory. In Table 3 m - and k_s - values are given for some defined load and boundary conditions. Note that the greatest m-value is to be applied for 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 3 Values of m and k_s

Load and boundary conditions			*Bending moment and shear force factors*		
Positions			1 m_1 k_{s1}	2 m_2 –	3 m_3 k_{s3}
1 Support	2 Field	3 Support			
			85 0.50	42	85 0.50
			0.38	70	125 0.63
			0.50	125	0.50
			65 0.30	43	100 0.70

Load and boundary conditions	*Bending moment and shear force factors*		
	0.20	60	135 0.80
	0.33	130	0.67

2.2.4 The m and k_s values referred to in [2.2.1] and [2.2.2] are normally to be as given in Table 4 for various structural items.

Table 4 Values of m and k_s for various structural items

Item		*m*	k_s
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 ends	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

2.2.5 Girders supporting other girders or a pillar are to have a section modulus:

$$Z = \frac{1000 P S}{m \sigma f_1} \ (cm^3)$$

P = force from supported girder or pillar (kN)
m = 5.5 for force at half-span with half restrained ends
σ = as given in Sec.5 Table 1 for continuous longitudinal girders
= 160 for other girders
= 220 for watertight bulkheads, except the collision bulkhead, when the flooding load is applied

The effective web area shall not to be less than:

$$A_w = \frac{10\, k_s P}{\tau\, f_1} \quad (cm^2)$$

k_s = shear factor
= 0.55 for P approximately at half-span
τ = according to Table 2

For girders also laterally loaded, the value of Z and A_w are to be added to the lateral load requirements in [2.2.1] and [2.2.2]

2.3 Minimum thicknesses and geometrical ratios

2.3.1 The minimum thickness of web plates and brackets will be related to web depth and web stiffeners spacing as described in Sec.1 [9.6].

2.3.2 Girder flanges are to have a thickness not less than 1/30 of the flange width when the flange is symmetrical, and not less than 1/15 of the flange width when the flange width is asymmetrical. And for bottom transverses a width not less than 1/20 of the distance between tripping brackets (side girders).

2.4 Weather deck hatch covers. Shell doors

2.4.1 Girders, including edge stiffeners, supporting cover or door stiffeners are to have a section modulus as given by [2.2.1]. In addition the moment of inertia is not to be less than:

$$I = 1.7\ Z\ l\ (\text{cm}^4)$$

2.4.2 To ensure sufficient packing pressure for the whole distance between the securing devices, the moment of inertia of the side elements of the covers is to be at least:

$$I = 6\ p_l\, a^4\ (\text{cm}^4).$$

for cover edges connected to a rigid hatch coaming and

$$I = 12\ p_l\, a^4\ (\text{cm}^4).$$

between cover edges of equal stiffness both deflecting under the packing pressure

p_l = packing line pressure along edges in N/mm, minimum 5 N/mm
a = spacing in m of bolts or other securing devices.

2.4.3 For edge stiffeners supporting cover or door stiffeners between securing devices, the moment of inertia is to be increased corresponding to the extra force.

2.4.4 The design force for securing bolts and other closing devices of doors opening inwards, their supporting members and surrounding structure is given by:

$$F = k\,A\,p\ 10^{\ 3} + a\ p_l\ (\text{N})$$

k = fraction of A supported by bolt or device
A = area of door in m^2.

p is normally to be calculated at the midpoint of A.

a = spacing of bolts in m
p_l = packing line pressure in N/mm. For calculation purpose, however, the packing pressure is not to be taken less than 5 N/mm.

2.4.5 Net bolt area for each bolt is not to be less than:

$$A_c = \frac{0,01\,F}{\sigma\, f_{1e}} \quad (cm^2)$$

F is as calculated in [2.4.4].

s = 125

f_{1e} = $\left(\frac{\sigma_f}{235}\right)^e$

σ_f = minimum upper yield stress in N/mm^2, not to be taken greater than 70 % of the ultimate tensile strength

e = 0.75 for $\sigma_f > 235$
= 1.0 for $\sigma_f < 235$

2.4.6 The maximum stresses in closing devices of other types than bolts are:

Normal stress:

$$\sigma = 120\, f_{1e}\ (\text{N/mm}^2)$$

Shear stress:

$$\tau = 80\, f_{1e}\ (\text{N/mm}^2)$$

2.4.7 For hatch covers carrying deck cargo, special calculations will be required, both for the downward and upward reaction forces and for horizontal sliding forces.

2.5 Doors in watertight bulkheads

2.5.1 Girders, including edge stiffeners, supporting door stiffeners are to have a section modulus as given in [2.2.1]. In addition, edge stiffeners of doors are to have a moment of inertia not less than:

$$I = 8 \cdot p_e \cdot d^4 [\text{cm}^4]$$

d = distance between closing devices in m, to be measured along the door edge
p_e = packing line pressure along edges, not to be taken less than 5 N/mm.

2.5.2 For edge stiffeners supporting main door stiffeners between securing devices, the moment of inertia is to be increased corresponding to the extra force.

SECTION 7 STEEL PILLARS AND PILLAR BULKHEADS

1 General

1.1 Introduction

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

1.2 Definitions

1.2.1 Symbols:

L, B, D, T, C_B, see Ch.1.

t = thickness in mm of plating
s = stiffener spacing in m, measured along the plating
= 2 (240 + L) (mm)
l = length of pillars, cross ties, bulkhead stiffeners etc. between effective supports normal to their axis in m
I = smallest moment of inertia in cm^4, including 20 x t plating each side of bulkhead stiffener
A = cross-sectional area in cm^2, including 20 x t plating each side of bulkhead stiffener
i = $\sqrt{\frac{I}{A}}$ = radius of gyration in cm
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. Otherwise beams or girders in deck in way 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 may have to be fitted dependent on support at the top and the bottom of the pillars. 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 Pillar scantlings

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

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

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

P = axial load in kN as given for various strength members in [2.2.2] and [2.2.3]. Alternatively, P may be obtained from direct stress analysis

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

σ_c = σ_E when $\sigma_E < \frac{\sigma_F}{2}$ (N/mm^2)

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

σ_E = $\pi^2 E\left(\frac{i}{100\,l}\right)^2$ (N/mm^2)

σ_F = minimum upper yield stress of material

E = modulus of elasticity for steel = 210 000 N/mm^2.

The formula given for σ_E is based on hinged ends and axial forces only.

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

If it is verified that both ends can be regarded as fixed, the value of σ_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.

2.2.2 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 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):

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

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

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

2.2.3 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)

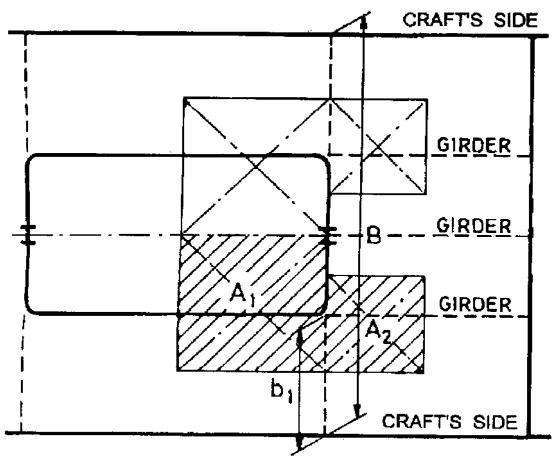


Figure 1 Deck with transverse beams

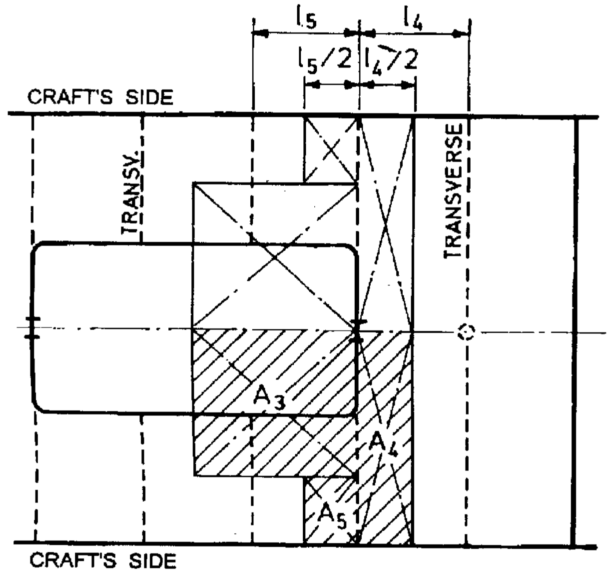


Figure 2 Deck with longitudinals

2.3 Pillars in tanks

2.3.1 Hollow pillars are not accepted.

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

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

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

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

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.

SECTION 8 WELDING AND WELD CONNECTIONS

1 General

1.1 Introduction

1.1.1 In this section requirements related to welding and various connection details are given.

1.2 Welding particulars

1.2.1 Welding at ambient air temperature of –5°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 is possible, contract freely in order to avoid cracks in already deposited weld runs. Where a butt meets a seam, the welding of the seam should be interrupted well clear of the junction and not be continued until the butt is completed. Welding of a butt should continue past the open seam, and the weld then chipped out, so that the seam can 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 type approved products No.2, welding consumables*.

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 edges prepared as indicated in Figure 1.

2.1.2 For butt welded joints of plates with thickness difference exceeding 4 mm, the thicker plate is normally to be tapered. The taper is generally not to exceed 1:3. After tapering, the end preparation may be as indicated in [2.1.1] for plates of equal thickness.

2.1.3 All types of butt joint are normally to be welded from both sides. Before welding is carried out from the second side, unsound weld metal is to be removed at the root by a suitable method.

2.1.4 Butt welding from one side only will be permitted after special consideration where a backing run is not practicable or in certain structures when the stress level is low.

2.2 Lap joints and slot welds

2.2.1 Various types of overlapped joints are indicated in Figure 2. Type “A” (lap joint) is normally not to be used in primary structures. Provided the dynamic stress levels are low, lap joints may be accepted on special considerations. Type “B” (slot weld) may be used for connection of plating to internal webs, where access for welding is not practicable. For size of slot welds, see [3.1.3].

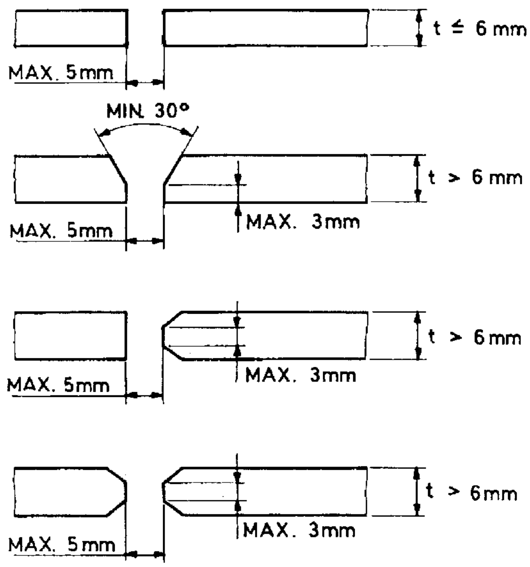


Figure 1 Manually welded butt joint edges

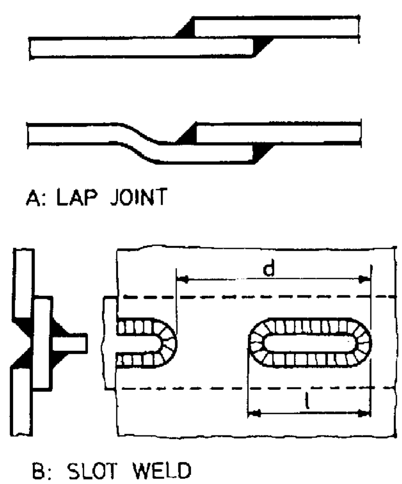


Figure 2 Lap joints and slot welds

2.3 Tee or cross joints

2.3.1 The connection of girder and stiffener webs to plate panel, as well as plating abutting on another plate panel, is normally to be made by fillet welds as indicated in Figure 3.

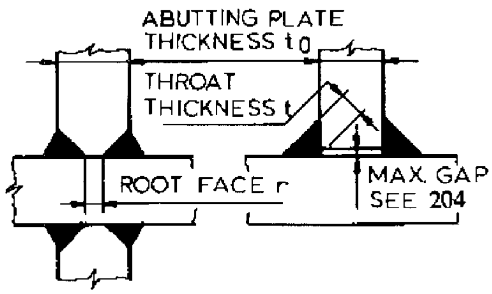


Figure 3 Tee or cross joints

Where the connection is highly stressed or otherwise considered critical, the edge of the abutting plate may have to be bevelled to give deep or full penetration welding. Where the connection is moderately stressed, intermittent welds may be used. With reference to Figure 4, the various types of intermittent welds are as follows:

— chain weld
— staggered weld
— scallop weld (closed). For size of welds, see [3.1.2].

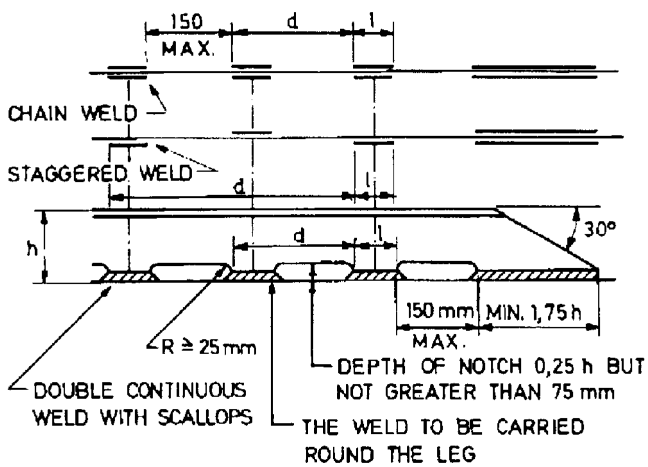


Figure 4 Intermittent welds

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

— weathertight, watertight and oiltight connections
— connections in foundations and supporting structures for machinery
— all connections in after peak
— connections in rudders, except where access difficulties necessitate slot welds
— connections at supports and ends of stiffeners, pillars, cross ties and girders
— centre line girder to keel plate
— water jet duct structure and structure adjacent to the water jet duct.

2.3.3 Where intermittent welds are accepted, scallop welds are to be used in tanks for water ballast, cargo oil or fresh water. Chain and staggered welds may be used in dry spaces and tanks arranged for fuel oil, only.

3 Load based weld scantlings

3.1 Joints of abutting webs or plates

3.1.1 The throat thickness of double continuous fillet welds is not to be less than:

$$t = \frac{C\,t_0}{f} \text{ (mm)}$$

C = weld factor given in Table 1
t_0 = net thickness in mm of abutting plate

For plate thicknesses (t_n) above 22 mm, t_0 may be substituted by 0.5 (22 + t_n)

f = 1.36 for VL-NS and weld deposit yield strength ≥ 355 N/mm^2
= $\frac{f_w}{\sqrt{f_{pm}}}$ in other cases

f_{pm} = material factor f_1 as defined in Sec.2 [2.3] for plates to be joined
f_w = material factor for weld deposit
= $\left(\frac{\sigma_{fw}}{235}\right)^{0,75}$

s_{fw} = yield strength in N/mm^2 of weld deposit, not to be taken higher than 1.5 times the yield strength of the material to be welded

Table 1 Weld factor C

Item		*60 % of span*	*At ends*
Stiffeners, frames, beams, longitudinals to shell, deck or bulkhead plating		0.16	0.26
Web plates of girders	To plating	0.26	0.43
	To flange	0.16	0.26
Webs of girders supporting other girders, — to the plating — to the flange		0.43 0.26	
Bulkhead boundary connections	Tank and watertight bulkheads	0.52	
	Pillar bulkheads	0.16	
	Superstructure end, deckhouse external and machinery casing bulkheads to deck below	0.52	
Strength deck to shell		0.68	

Item		60 % of span	At ends
Weather or tank decks to shell		0.52	
Hatch coaming to strength deck	At corners	0.68	
	Elsewhere	0.52	
Weather hatch coaming top profile to coaming		0.52	
Sea inlets		0.68	
Scuppers and discharges to deck and shell		0.52	

3.1.2 The throat thickness of intermittent fillet welds, when permitted according to [2.3.2], is not to be less than:

$$t = \frac{t_0\, d\, C}{f\, l} \quad \text{(mm)}$$

C, t_0 and f are as given in [3.1.1].

d = distance, in mm, between successive welds, see Figure 4
l = length, in mm, of weld fillet, not to be less than 75 mm

If the required t exceeds:

— 0.6 t_0 for chain and scallop weld
— 0.75 t_0 for staggered weld

intermittent weld cannot be applied. In addition, in the slamming area the ratio d/s should not exceed:

— 1.25 forward of amidships
— 1.7 aft of amidships.

3.1.3 *Fillets welds in slots* are to have a throat thickness as given by the formula in [3.1.2] with:

t_0 = net thickness of adjoining web plate
d = distance between slots
l = length of slots

Slots are to have a minimum length of 75 mm and, normally, a width of twice the plate thickness. The ends are to be well rounded, see Figure 2. The distance d between slots is not to exceed 3 l, maximum 250 mm.

3.1.4 When K-weld is used in a heavily shear loaded tee or cross joint, e.g. unsymmetrical or symmetrical bulkhead girders, the visible throat thickness after welding may be reduced by the depth of the bevelling.

3.1.5 When fillet weld, K-weld or full penetration weld is used in an axially loaded cross joint, the visible throat thickness, see Figure 5, is not to be less than:

$$t = \frac{C\, t_0}{f_w} \ \text{(mm)}$$

C = $0,27 + \left(\frac{\sigma}{200} - 0,34\right)\frac{r}{t_0}$

σ = calculated maximum tensile stress in abutting plate in N/mm^2, minimum 70
r = root face in mm
t_0 = net thickness in mm of abutting plate
f_w = as given in [2.1.1].

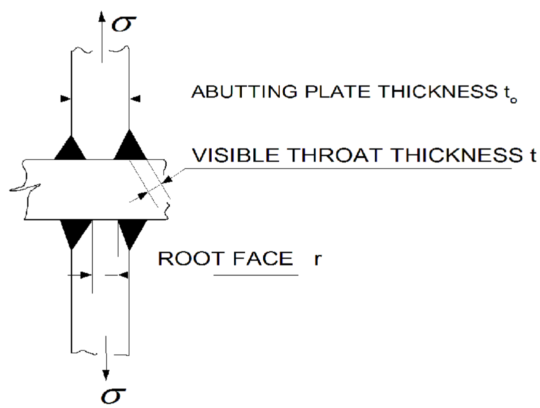


Figure 5 Axially loaded cross joint

3.1.6 Full penetration welds are in any case to be used in the following connections:

— shaft brackets to reinforced shell structure
— rudder side plating to rudder stock and other important connection areas of rudders, rudder suspension members, propeller ducts etc.
— end brackets of hatch side coamings to deck and coaming and other heavily shear loaded spots
— crane pedestal if abutting to deck plating
— penetrating type edge reinforcements or pipe penetrations to strength deck (including sheer strake) and bottom plating within 0.6 L amidships, when transverse dimension of opening exceeds 300 mm
— fatigue critical parts of water jet ducts, where grinding of welds may become necessary in order to have sufficient fatigue strength.

3.2 Steel and weld support of stiffeners to girders

3.2.1 Stiffeners may be connected to the web of primary structure elements in the following ways:

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

In slamming areas, areas of vibration induced by the water jet impeller or propeller, tanks, car decks and other special locations, at least one side of the stiffener web should be connected.

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

3.2.2 The steel connection area at supports of stiffeners is normally not to be less than:

$$a_o = c \cdot k \cdot (l - 0.5 \cdot s) \cdot s \cdot p \ [\mathrm{cm}^2]$$

c = factor as given in Table 2
k = 0.125 for pressure acting on stiffener side and for slamming pressure
= 0.1 for other pressure acting on opposite side
l = span of stiffener in m
s = spacing between stiffeners in m
p = design pressure in kN/m^2

Table 2 c-factors

Type of connection (see Figure 6)	*Stiffener/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
"a" without stiffener web connection		1.50	1.25

3.2.3 Various standard types of connections are shown in Figure 6. Other types of connection will be considered in each case.

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

3.2.5 Weld area is not to be less than:

$$a = 0.85 \cdot a_0 \ (\mathrm{cm}^2).$$

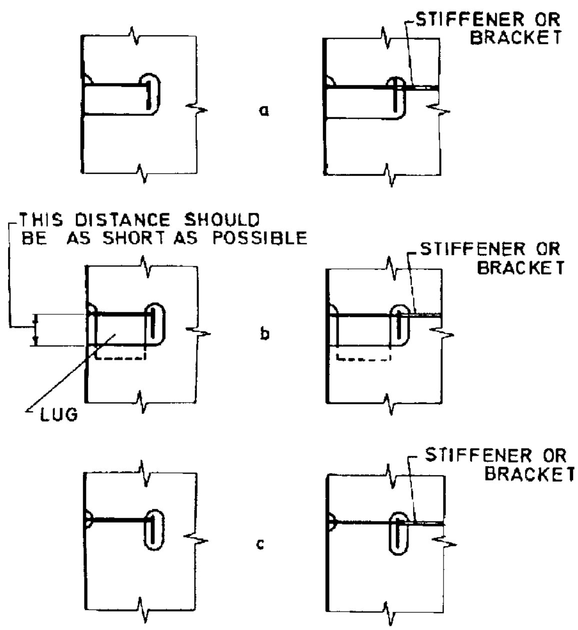


Figure 6 End connections

3.3 Steel and weld end connections of longitudinals

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

3.3.2 The weld area of brackets to longitudinals as well as the steel area of bracket through bulkhead is not to be less than the sectional area of the longitudinal. Brackets are to be connected to bulkhead by a double continuous weld.

3.3.3 When for L < 50 m and for larger craft outside 0.5 L amidships the bracket may be welded to each side of the bulkhead, the cross joint welding is to satisfy [3.1.5].

3.3.4 When no longitudinal on opposite side, see [3.4].

3.4 Weld end connections of stiffeners in general

3.4.1 The connection between stiffener and bracket is in general to be so designed that the effective section modulus is not reduced below the requirement for the stiffener.

3.4.2 When the plating supported by stiffener is continuous beyond end of span, see Figure 7, the weld area restraining the free edge of stiffener is not to be less than:

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

Z = net section modulus of stiffener in cm^3
h = stiffener height in mm
k = 15 in general
= 25 for connections restraining the lower end of lower side frames

(minimum weld area = 10 · s/s_r [cm^2])

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

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

A = 0.105 l s p (cm^2)
l, s and p = as given in [3.2.2].

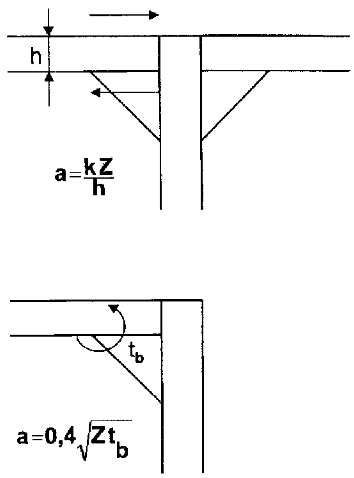


Figure 7 End connections

3.4.4 When the plating supported by stiffener terminates at the end of span, see Figure 7, e.g. deck at side, bulkhead at circumference, the weld area of the bracket arms is not to be less than:

$$a = 0,4\sqrt{Zt_b}\ (cm^2)$$

t_b = net thickness in mm of bracket.
Z = net section modulus of stiffener in cm^3.

3.5 End connections of girders, pillars and cross ties

3.5.1 The weld connection area of bracket to adjoining girders and of bracket and girder to other structural parts may be based on directly calculated normal and shear stresses. Double continuous welding is to be used. Where large tensile stresses are expected, welding according to [3.1.5] is to be applied.

3.5.2 The end connections of simple girders are to satisfy the requirements for section modulus given for the girder in question. For brackets overlap welded to rolled sections the formulae of [3.4.2] and [3.4.4], as relevant, may be used.

Where high shear stresses in web plates, double continuous boundary fillet welds are to have throat thickness not less than:

$$t = \frac{\tau\, t_0}{200 f_w} \quad \text{(mm)}$$

τ = calculated shear stress in N/mm^2
t_0 = net thickness of abutting plate
f_w = as given in [1.2].

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

$$a = \frac{k\,A\,p}{f_w} \quad (cm^2)$$

A = load area in m^2 for pillar or cross tie
p = design pressure in kN/m^2 as given for the structure in question
f_w = as given in [1.2]
k = 0.05 when pillar in compression only
= 0.14 when pillar in tension.

4 Minimum weld scantlings

4.1 Minimum fillet weld

4.1.1 In no case the throat thickness of double continuous fillet welds is to be taken less than given in Table 3.

Table 3

Plate thickness (web thickness) t_0 (mm)	*Minimum throat thickness (mm)*	
	Arc welding with covered electrodes	*Gas shielded arc welding*
$t_0 \leq 4$		2.0
$4 < t_0 \leq 6.5$	3.0	2.5
$6.5 < t_0 \leq 8$	3.0	
$t_0 > 8$	$0.21\ t_0$, minimum 3.25	

4.1.2 For intermittent fillet weld, the throat thickness is not to be less than 3.5 mm. For maximum thickness of intermittent weld, see [3.1.3].

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, 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 rule requirements are given in this section. Load conditions, allowable stresses and applicable calculation methods are specified.

It is also referred to Ch.9 which specifies requirements for direct calculations procedures of hydrodynamic and strength analyses as well as requirements for local finite element models which are applicable for the local analyses as described in this section.

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 optimization 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, or shear, stresses is specified in Sec.10.

3 Stiffeners

3.1 General

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

— stiffeners affected by supports with different deflection characteristics
— stiffeners subject 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.10.

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 element models or finite element analyses 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 Sec.3 for the structure in question.

3.3.2 The magnitude and sign of hull girder stress acting simultaneously, will have to be decided in each case. It is also referred to Ch.9, which gives guidance for how this is to be done.

3.3.3 For double bottom and other cofferdam type structures, a cofferdam bending moment and a shear force induced stiffener bending moment may have to be considered at the same time.

3.4 Allowable stresses

3.4.1 The allowable stress level is as given in Table 1.

Table 1 Maximum allowable stresses

Nominal local bending stress	General	σ = 180 f_1 N/mm^2
	Watertight bulkheads, except collision bulkhead	σ = 245 f_1 N/mm^2
Combined local bending stress/girder stress/extreme longitudinal stress		σ = 230 f_1 to 265 f_1 N/mm^2, see reference in [4.4.5]
Nominal shear stress	General	τ = 90 f_1 N/mm^2
	Watertight bulkheads, except collision bulkhead	τ = 120 f_1 N/mm^2

3.4.2 Stiffeners are in no case to have web and flange thicknesses less than given in Sec.5 [3] for the structure in question.

4 Girders

4.1 General

4.1.1 For girders 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 have to be carried out for:

— bottom structures
— side structures
— deck structures
— bulkhead structures
— transverse frame structures in monohull craft supporting deckhouses, containers and other permanent or cargo masses subject to tripping
— strength of deck along wide hatches, see Sec.6 [2]
— other structures when deemed necessary by the Society.

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 rise of floor bottoms, shear in the bottom plating will resist vertical deflection of the keel, with a releasing effect on the longitudinal girder, which may be taken into account.

4.2.3 For deep girders, bulkhead panels, bracket zones, etc. where results obtained by applying the beam theory are unreliable, finite element analysis, see Ch.9, or equivalent methods are to be applied.

4.2.4 Acceptable calculation methods are outlined in classification notes.

4.3 Design load conditions

4.3.1 The calculations are to be based on the loads at design level as given in Ch.1. Except for monohull horizontal accelerations, which are given in SHIP Pt.3 Ch.4 (extreme values).

Horizontal accelerations may also be based on a hydrodynamic analysis as described in Ch.9.

For sea-going conditions realistic combinations of external and internal dynamic loads and inertia forces are to be considered.

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

4.4 Allowable stresses

4.4.1 The equivalent stress is defined as:

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

σ_x = normal stress in x-direction
σ_y = normal stress in y-direction
τ = shear stress in the xy-plane

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

Normal stress:

$\sigma = 160\ f_1\ N/mm^2$

Mean shear stress:

$\tau = 90\ f_1\ N/mm^2$ for girders with one plate flange
$\tau = 100\ f_1\ N/mm^2$ for girders with two plate flanges

Equivalent stress:

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

4.4.3 For girders on watertight bulkheads:

- σ and σ_e may be increased by 60 f_1 N/mm^2.
- τ may be increased by 30 f_1 N/mm^2.

except for the collision bulkhead.

4.4.4 For transverse structures and partial longitudinal structures supporting deckhouses, containers etc. in the rolling and pitching conditions:

- σ and σ_e may be increased by 50 f_1 N/mm^2.
- τ may be increased by 25 f_1 N/mm^2.

when extreme horizontal accelerations have been applied.

4.4.5 For girders subjected to hull girder stresses, the following additional requirement applies:
$\sigma_e = 90\ f_1\ N/mm^2$.
plus maximum allowable longitudinal stress according to Sec.4 [2.1.1] or maximum allowable transverse stress according to Sec.4 [5.2.2].
The actual longitudinal or transverse stress in the girder is taken from the calculations in Sec.4.

4.4.6 In compression, the buckling stress may be decisive. See Sec.10.

4.5 Allowable deflections

4.5.1 For deflections in general, see Sec.1 [11].

4.5.2 For weather deck hatch coamings, the horizontal deflection at weather tightening level should not exceed 25 mm, unless tightness at a greater deflection may be proved.

4.5.3 For weathertight and watertight hatches and doors, the relative deflection of cover and hull coamings in the pressure direction should not result in leakage due to loss of packing pressure.

4.5.4 Deflection limits of girders and coamings of covers and doors themselves are found in Sec.5 and Sec.6 in terms of a moment of inertia requirement.

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
= $2.06 \cdot 10^5$ N/mm^2 for steel
σ_{el} = the ideal elastic (Euler) compressive buckling stress in N/mm^2
σ_f = minimum upper yield stress of material in N/mm^2, may be taken as 235 N/mm^2 for normal strength steel. For higher strength steel, see Sec.2 [2]
τ_{el} = the ideal elastic (Euler) shear buckling stress in N/mm^2
τ_f = minimum shear yield stress of material in N/mm^2
= $\frac{\sigma_f}{\sqrt{3}}$
σ_c = the critical compressive buckling stress in N/mm^2
τ_c = the critical shear stress in N/mm^2
σ_a = calculated actual compressive stress in N/mm^2
τ_a = calculated actual shear stress in N/mm^2
η = $stability\ (usage)\ factor = \frac{\sigma_a}{\sigma_c} = \frac{\tau_a}{\tau_c}$
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 σ_c or τ_c is known, the necessary σ_{el} or τ_{el} will from the above expressions of the Johnson-Ostenfeld relationship be:

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

K_{J-O} from Figure 1 or from the formula:

$$K_{J-O} = 1 - \left(\frac{\sigma_c \text{ or } \tau_c}{0,5(\sigma_f \text{ or } \tau_f)} - 1\right)^2$$

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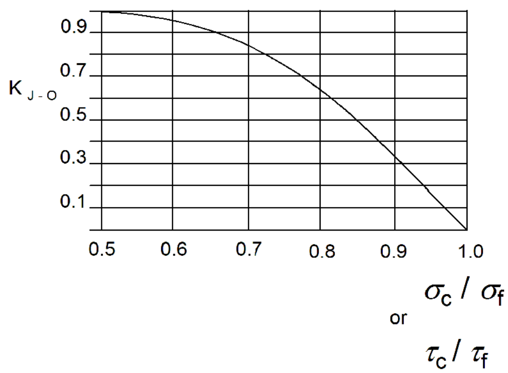

Figure 1 Johnson-Ostenfeld K-factor

$$\text{For } \frac{\sigma_c}{\sigma_f} < 0,5, \quad K_{J-O} = 1$$

2 Longitudinal buckling load

2.1 Longitudinal stresses

2.1.1 See Pt.3 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 Pt.3 Ch.1 Sec.4 [2]
— supports of craft's side structure, Sec.5 and Sec.6.

4 Plating

4.1 Plate panel in uni-axial compression

4.1.1 The ideal elastic buckling stress may be taken as:

$$\sigma_{el} = 0,9\,k\,E\left(\frac{t}{1000s}\right)^2 \quad (N/mm^2)$$

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

$$k = k_l = \frac{8,4}{\psi + 1,1}\ for\ (0 \le \psi \le 1)$$

For plating with transverse stiffeners (perpendicular to the compression stress):

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

c = 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.
ψ = the ratio between the smaller and the larger compression stress assuming linear variation, see Figure 2.

The above correction factors are not valid for negative ψ-values.

The critical buckling stress is found from [1.1.2].

4.1.2 The critical buckling stress is to be related to the actual compression stresses as follows:

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

σ_a = calculated compression stress in plate panels. With linearly varying stress across the plate panel, σ_a is to be taken as the largest stress
η = 1.0 for deck, side, single bottom and longitudinal bulkhead plating
= 0.9 for bottom and inner bottom plating in double bottoms
= 1.0 for locally loaded plate panels where an extreme load level is applied
= h_G for locally loaded plate panels where a normal load level is applied (e.g. plating acting as effective flange for girders)
η_G = $(p_s + 0.5\ p_d) / (p_s + p_d)$

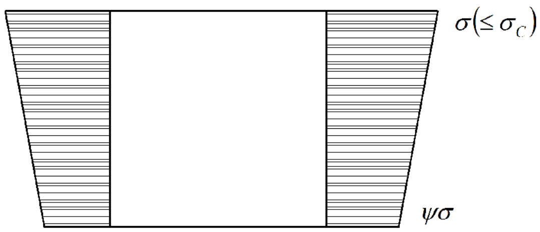

Figure 2 Buckling stress correction factor

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 compression stress:

$$t = 1,17\,s\sqrt{\frac{\sigma_c}{K_{J-O}}}\ \text{(mm)}$$

σ_c according to [4.1.2]

K_{J-O} from Figure 1

— with stiffeners perpendicular to compression stress:

$$t = 2,33\frac{s}{1+\left(\frac{s}{l}\right)^2}\sqrt{\frac{\sigma_c}{cK_{J-O}}}\ \text{(mm)}$$

c according to [4.1.1].

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

4.1.4 For elastic buckling, see [7].

4.2 Plate panel in shear

4.2.1 The ideal elastic buckling stress may be taken as:

$$\tau_{el} = (0,9)k_t E\left(\frac{t}{1000s}\right)^2 \quad (N/mm^2)$$

k_t = $5.34 + 4(s/l)^2$

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

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

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

η = 0.90 for craft's sides and longitudinal bulkheads subjected to hull girder shear forces
= 0.95% η_G for local panels in girder webs when nominal shear stresses are calculated (τ_a = Q/A).
= η_G for local panels in girder webs when shear stresses are determined by finite element calculations or similar.

η_G as given in [4.1.2].

Guidance note:

The resulting thickness requirement will be:

$$t = 2,33\, s\sqrt{\frac{\tau_c}{k_t K_{J-O}}} \quad (mm)$$

τ_c according to [4.2.2]

K_{J-O} 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 and in addition to in-plane shear stresses the interaction is given by:

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

σ_{ax} = compression stress in longitudinal direction (perpendicular to stiffener spacing s)

σ_{ay} = compression stress in transverse direction (perpendicular to the longer side *l* of the plate panel)
σ_{cx} = critical buckling stress in longitudinal direction as calculated in [4.1]
σ_{cy} = critical buckling stress in transverse direction as calculated in [4.1].

τ_a and τ_c are as given in [4.2].

η_x, η_y = 1.0 for plate panels where the longitudinal stress σ_a (as given in Pt.3 Ch.1 Sec.4 [1.7]) or other extreme stress is incorporated in and constitutes a major part of σ_{ax} or σ_{ay}
= 0.95 η_G in other cases.

η_G as given in [4.1.1].

$K = c\,\beta^a$

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 a, c and n

	c	*a*	*n*
1.0 < *l*/s < 1.5	0.78	– 0.12	1.0
1.5 ≤ *l*/s < 8	0.80	0.04	1.2

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

η_t = h as given in [4.2].

Only stress components acting simultaneously are to be inserted in the formula.

For plate panels in structures subject to longitudinal stresses, such stresses are to 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:

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:

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

i = $\sqrt{\frac{I_A}{A}}$
I_A = moment of inertia in cm^4 about the axis perpendicular to the expected direction of buckling
A = cross-sectional area in 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 σ_{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 is to be reinforced to withstand bending stresses.

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

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

σ_a = calculated extreme compression stress, or ordinary local load stress divided by η_G from [4.1]
η = 0.85 for continuous stiffeners
= 1− η_b, maximum 0.85, for single-span stiffeners
η_b = (simultaneous bending moment at midspan)/(bending capacity)

Guidance note:

The resulting maximum allowable slenderness will be:

$$100 \frac{l}{i} = 1435 \sqrt{\frac{K_{J-O}}{\sigma_c}}$$

σ_c according to [5.1.2].

K_{J-O} from Figure 1.

---e-n-d---of---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 compression stresses, the ideal elastic buckling stress for the torsional mode may in general be calculated from formulae in SHIP Pt.3 Ch.8.

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

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

σ_a = calculated extreme compression stress, or ordinary local load stress divided by η_G from [4.1]

η = 0.85 in general.

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

Guidance note:

Flats

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

$$h_w = t_w \frac{245}{\sqrt{\frac{\sigma_c}{K_{J-O}}}} \quad \text{(mm)}$$

t_w = thickness of web in mm

σ_c = according to [5.2.2]

K_{J-O} from Figure 1.

Flanged profiles $1 < \frac{h_w}{b_f} < 3$:

Minimum flange breadth may be taken as:

For symmetrical flanges:

$$b_f = 3l\sqrt{\frac{\sigma_c}{K_{J-O}}} \quad \text{(mm)}$$

For unsymmetrical flanges:

$$b_f = 2l\sqrt{\frac{\sigma_c}{K_{J-O}}} \quad \text{(mm)}$$

σ_c = according to [5.2.2]

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 σ_{el}-value required for the web buckling mode may be taken as:

$$\sigma_{el} = 3,8E\left(\frac{t_w}{h_w}\right)^2 \quad (N/mm^2)$$

t_w, h_w = web thickness and height in mm

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

$$\sigma_{el} = 0,38E\left(\frac{t_f}{b_f}\right)^2 \quad (N/mm^2)$$

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 σ_c found from [1.1.2] is not to be less than as given in [5.2.2].

Guidance note:

— For web thickness, see plating with stiffener in direction of compression stress, [4.1.3].

Flange width from web:

$$b_f < t_f \frac{245}{\sqrt{\frac{\sigma_c}{K_{J-O}}}} \quad \text{(mm)}$$

σ_c = according to [5.2.2]
K_{J-0} = according to Figure 1.

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

6 Stiffeners Perpendicular to Direction of Compression

6.1 Moment of inertia of stiffeners

6.1.1 For stiffeners supporting plating subjected to compression stresses perpendicular to the stiffener direction, the moment of inertia of the stiffener section (including effective plate flange) is not to be less than:

$$I = \frac{0,09\sigma_a\sigma_{el}\ l^4 s}{t}\ (cm^4)$$

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

σ_{el} = $\frac{\sigma_c}{K_{J-O}}$

σ_c = $\frac{\sigma_a}{0,85}$

σ_a = actual extreme compression stress, or ordinary local load stress divided by η_G from [4.1]
$K_{J—O}$ = 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 ηG for ordinary local load
  $\eta\ \sigma_{el}$ from [4] and [1.1.2]
- there are no functional requirements prohibiting the deflections
- extreme loads are used in the calculations.

Guidance note:

The torsional buckling mode of flats may be taken as:

$$\sigma_{el} = 0,385E\left(\frac{t_w}{h_w}\right)^2 (N/mm^2)$$

---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 compression force in the panel may be increased from:

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

to:

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

$$\dot{0}1(h_s \sigma_c - \eta_p \sigma_{el})\left(\frac{b_e}{b} A_p + A_s\right)\ (kN)$$

η_p, η_s = η for plating and stiffener from [4] and [5]. η_s to be multiplied by η_G for ordinary local load

$\sigma_{el}\ \sigma_c$ = for plating and stiffener, respectively, from [4] and [5]. Ordinary effective flange is to be used for stiffeners

A_p, A_s = area of plating and stiffener in cm^2

b_e/b = fraction of A_p participating in the post-buckling stress increase

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

σ_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 (compression 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 = $0.75(l/s+1)$

A_s = 0

resulting in:

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

7.2.3 σ_u may be substituted for σ_{el} when calculating bi-axial compression and shear in [4.3].

8 Girders

8.1 Axial load buckling

8.1.1 For lateral, torsional, web and flange buckling, see [5].

8.2 Girders perpendicular to direction of compression

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

$$\sigma_{el} = 4{,}12\frac{\pi^2}{S^2(t+t_a)}\sqrt{\frac{I_a I_b}{sl}}\ (N/mm^2)$$

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

S = span in m of girder
l = distance in m between girders
s = spacing in m of stiffeners
I_a = moment of inertia of stiffener in cm^4
I_b = moment of inertia of transverse girder in cm^4
t = plate thickness in mm
t_a = equivalent plate thickness of stiffener area in mm (smeared out thickness of stiffener).

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

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

σ_a = calculated compression stress
η = 0.75.

8.3 Buckling of effective flange

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

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

η_G as given in [4.1.2].

8.3.3 The critical buckling strength is given in [4.1], when l = span of stiffener or distance from girder to buckling stiffener parallel to the girder, if any.

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 considered, a reduced l may be considered in formula.

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

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