Polski Rejestr Statków

RULES
FOR THE CLASSIFICATION AND CONSTRUCTION OF NAVAL SHIPS

PART II
HULL

2008

GDAŃSK

RULES FOR THE CLASSIFICATION AND CONSTRUCTION OF NAVAL SHIPS prepared and issued by Polski Rejestr Statków S.A., hereinafter referred to as PRS, consist of the following Parts:

Part I – Classification Regulations
Part II – Hull
Part III – Hull Equipment
Part IV – Stability and Subdivision
Part V – Fire Protection
Part VI – Machinery Installations and Refrigerating Plants
Part VII – Machinery, Boilers and Pressure Vessels
Part VIII – Electrical Installations and Control Systems
Part X – Statutory Equipment

while with respect to materials and welding the requirements of *Part IX – Materials and Welding,* of the *Rules for the Classification and Construction of Sea-going Ships,* apply.

Part II – Hull – 2008, was approved by the PRS Board on 24 June 2008 and enters into force on 1 August 2008.

From the entry into force, the requirements of this Part II apply to:

- new naval ships, for which the building contract is signed on 1 August 2008, or after that date – in full scope,
- existing naval ships – in accordance with the principles specified in *Part I – Classification Regulations.*

The requirements of the present *Part* are extended and supplemented by documents referred to in particular *Parts of the Rules,* and particularly standard NATO agreements, national standards as well as the below-listed Publications:

Publication 9/P – Requirements for Computer Based Systems
Publication 11/P – Enviromental Tests on Marine Equipment
Publication 14/P – Principles of Approval of Computer Programs
Publication 16/P – Loading Guidance Information
Publication 21/P – Testing of the Hull Structures
Publication 24/P – Container Ship Hull Strength Analysis (in Polish only)
Publication 32/P – Requirements Concerning Stowage and Lashing of Cargoes on Sea-going Ships
Publication 40/P – Non metallic Materials
Publication 45/P – Fatique Strength Analysis of Steel Hull Structure

PRS/AW, 03/2010
ISBN 978-83-7664-035-8

CONTENTS

A GENERAL

1 APPLICATION

1.1 The present *Part II – Hull* applies to steel welded hulls of naval displacement ships with maximum speed meeting a condition:

$$V_{max} < 7.20 \cdot V^{0.1667} \text{, [knots]} \quad (1.1)$$

1.2 The allowable ranges of the ship main dimensions and their ratios are specified, where necessary, in relevant Chapters of the present *Rules for the Classification and Construction of Naval Ships* (further referred to as the *Rules*). Ships and structures of unconventional design or those exceeding limits of parameters specified in the present Part of the Rules will be considered by the PRS.

1.3 The present *Part II* of the *Rules* may also be applied to hull structures made of aluminium alloys. Application of materials other than aluminium alloys will be separately considered by PRS.

1.4 The present *Part of the Rules* includes basic, additional and special requirements. Compliance with basic requirements (Chapter B), in an applicable scope, is obligatory for assignment of the main symbol of ships' class.

Additional marks in the symbol of class determining the designation of a ship, application of ice strengthening and adaptation of the hull structure to specific operating conditions will be affixed, provided the additional requirements (Part C) are complied with, where applicable.

Note:
In the present *Part II* references made to other places in *Part II* are supplemented with relevant letter (A, B or C), describing section, to which the reference relates. The letter is not given when the reference relates to the paragraph contained in the same section.

2 DEFINITIONS AND DESCRIPTIONS

2.1 General

Definitions relating to general terminology applied in the *Rules* are given in *Part I – Classification Regulations.* The present *Part of the Rules* introduce additional definitions and descriptions relating to the hull.

2.2 General Descriptions

FP – forward perpendicular – the perpendicular at the intersection of the waterline corresponding to design draught with the fore side of the stem. For ships with unconventional stem curvature, the position of the forward perpendicular will be specially considered by the PRS.

AP – after perpendicular – the perpendicular at the intersection of the waterline corresponding to design draught with the axis of the rudderstock or with transom line (in case of ships without classic rudders).

BL – baseline – horizontal plane which amidship crosses the top of a flat keel or the intersection of the inner surface of the plating with the bar keel.

L_o – design length of the ship, [m] – the length of the ship measured on a waterline plane corresponding to design draught from the fore edge of the stem to the axis of the rudderstock (to the transom – for ships without classic rudders). The assumed value of L_o is not to be les than 96% of the total length of the hull measured on a waterline plane as above, and must not be greater than 97% of that length. If a shape of the ships' bow or stern differs from usually applied, the length L_o – will be specially considered by PRS.

L_w – length of the ship measured on a waterline corresponding to design draught, [m] – the distance measured on this waterline from the fore edge of the stem to the point of intersection of the waterline with the after edge of the stern (transom).

L_{pp} – length between perpendiculars, [m] – the distance between the fore and aft perpendicular.

B – moulded breadth of the ship, [m] – the greatest moulded breadth measured between the outer edges of frames.

T – design draught, [m] – the vertical distance measured amidship from the baseline to the waterline at the maximum anticipated draught of the ship in normal service conditions.

H – moulded depth, [m] – the vertical distance measured amidship from the baseline to the upper edge of the uppermost deck's beam. For the ships with the rounded connection of the deck stringer and the shear strake, the moulded depth is to be measured to the intersection point of the deck line and side line extensions.

Where the upper deck is stepped, and through the point, in which the depth is to be assumed, passes upper part of the deck, the moulded depth is to be measured from the reference line constituting extension of the lower part parallel to the upper part of the deck.

D – moulded displacement, [t] – the weight of the ship, in tonnes, as the weight of water of capacity equal to the capacity of the submerged part of hull. If not defined otherwise salt water density of 1.025 t/m^3 is to be assumed.

D_p – full displacement of the ship, [t] – the displacement of fully equipped ship, with the crew, cargo, full supply of munitions, provisions and full stores of fuel, lubricants and boiler water.

V – volume of the moulded displacement [m^3] – the volume of a body defined by the external edges of frames at draught *T*.

δ – moulded block coefficient – the coefficient calculated from the formula:

$$\delta = \frac{V}{L_o B T}$$

v_{max} – maximum speed, [knots] – the speed achieved under continuous maximum power of the propulsion, at draught *T,* on still water.

v – ship speed, [knots] – the service speed of 0.9 v_{max}.

g – standard acceleration of gravity [m/s^2] – may be assumed as equal to 9.807 m/s^2.

R_e – material yield point, [MPa] – see *Part IX – Materials and Welding.*

k – material factor – a factor depending on material yield point – see 2.2.1.

E – elasticity (Young) modulus, [MPa] – for steel may be assumed as equal to $2.06 \cdot 10^5$, [MPa].

G – shear (Kirchoff) modulus, [MPa] – for steel may be assumed as equal to $G = 7.9 \cdot 10^4$, MPa.

x, y, z – co-ordinates of a point in the ship, [m] – see Fig. 2.3.1.

2.3 Co-ordinate System

2.3.1 In the present part of the Rules, the co-ordinate system, as can be seen on Fig. 2.3.1, has been assumed, which has the following reference planes: baseline, centreline and midship section.

The intersection of the centreline and the baseline forms the *x* axis of the positive sense forward.

The intersection of the baseline and midship section forms the *y* axis of the positive sense towards port side.

The intersection of the centerline and midship section forms the *z* axis of the positive sense upwards.

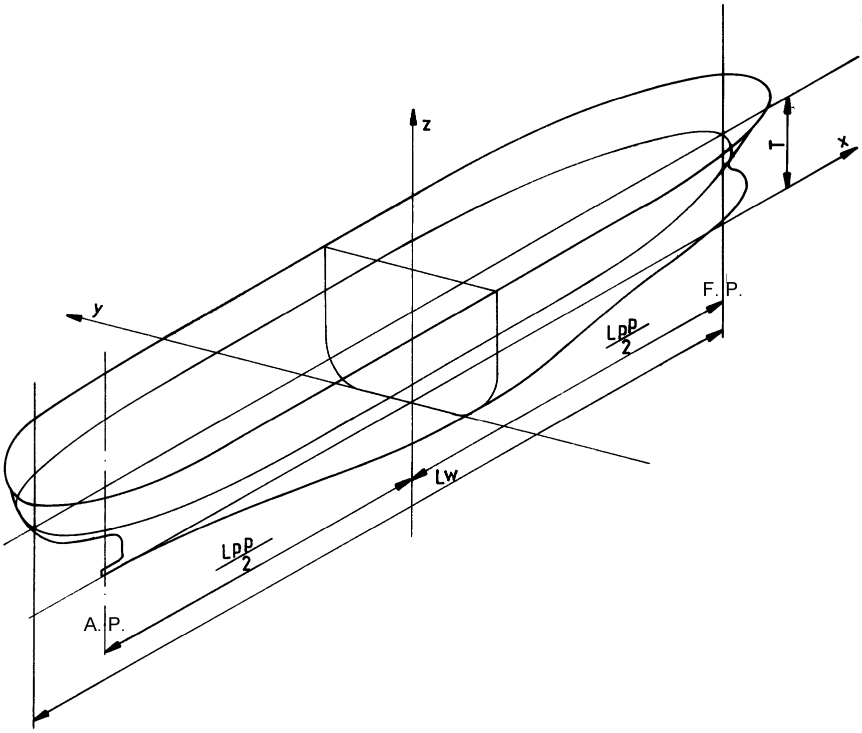


Fig. 2.3.1 Ship co-ordinate system

2.3.2 Other ship co-ordinate systems, specified separately, are also applicable to the present part of the *Rules*.

2.4 General Definitions

Moulded deck line – intersection line of surfaces defined by the external edges of deck beams and side frames. In the case of rounded deck corner, this is an intersection of extensions of these surfaces.

Deck erection – a part of the ship located above the upper deck, consisting of walls and covering deck. Deck erections are divided to superstructures, deckhouses and chests.

Superstructure – a decked structure on the upper deck, extending from side to side of the ship or with one side or both being inboard of the ship sides not more than 0.04*B*.
Depending on their location along the ship, the following definitions are applied:

Forecastle – an erection extending aft of the bow.

Poop – an erection extending forward of the stern.

Midship superstructure – an erection located partly or totally within the midship portion of the ship, it may be connected with the forecastle or the poop.

Midship plane – a transverse plane at the middle of the distance between the fore perpendicular and the aft perpendicular.

Platform deck – lower deck extending over a part of the ship's length or breadth, which does not need to be watertight.

Lower deck, 'tween deck – the deck situated below the upper deck. Where there are several lower decks, they are named: the second deck, the third deck, etc., counting from the upper deck.

Upper deck – the uppermost deck extending over the full length of the ship.

Bulkhead deck – the uppermost deck to which the main transverse watertight bulkheads are carried.

Superstructure (deckhouse) deck – the deck forming the top of a superstructure. Where the superstructure is divided into several tiers, the superstructure decks are named: first tier superstructure deck, second tier superstructure deck, etc., counting from the upper deck.

Weather deck (open) – each open deck or part thereof, which may be exposed to the effects of sea and weather.

Strength deck– the upper deck. Where it is covered by a midship superstructure which has the length not less than 3(0.5B + h), the midship superstructure deck is considered as the strength deck within this portion (h, [m] – the vertical distance between the upper deck and the midship superstructure deck in question). Any other deck may be defined as the strength deck within the given length of the ship upon special consideration of the ship's sides shear strength.

Deckhouse – a decked structure on the upper deck (or superstructure deck), with the sides being inboard of one or both ship sides more than 0.04 B.

Chest – a deck erection located similarly as a deckhouse, but without doors, windows and other similar openings in external walls.

Ship's end – a portion of the ship within $x < -0.4\ L_o$ or $x > 0.4\ L_o$. Where the extent of the portion in question is different, its co-ordinates are given in each particular case.

Midship portion – the ship portion of length equal to $0.4\ L_o$ (within $x < -0.2\ L_o$ or $x > 0.2\ L_o$) symmetrical in relation to the midship plane. Where the extent of the portion in question is different, its co-ordinates are given in each particular case.

Design waterline – a waterline corresponding to a design draught.

2.5 Definitions of Structural Members

Wash bulkhead – a perforated or partial bulkhead in a tank.

Watertight bulkhead – the transverse bulkhead dividing the hull into watertight compartments.

Side structure – shell plating including stiffeners and girders, between the uppermost deck reaching the side and upper turn of bilge in the case of single bottom or inner bottom plating in the case of double bottom.

Bulkhead structure – transverse or longitudinal bulkhead plating, including stiffeners and girders.

Single bottom structure – shell plating with stiffeners and girders below the upper turn of the bilge.

Double bottom structure – shell plating and inner bottom plating including stiffeners, girders and other elements below the top of inner bottom.

Superstructure (deckhouse) structure – wall plating, including the stiffeners and girders.

Deck structure – deck plating, including stiffeners and girders.

Stiffeners – a general name for structural members supporting directly the plating.

Simple girder – a girder, the conditions of ends fixation of which are known with sufficient accuracy and therefore it may be regarded as a member separated from the adjacent girders system.

Girders – a general name for structural members supporting the stiffener systems or other girders.

Main frames – side frames located outside the peaks area connected to the floors or the double bottom and carried to the lowest deck or side stringer if it is regarded as the frame support.

Tween deck frames – frames located between the supporting side stringers, between the supporting side stringer and the nearest deck or between the two decks, including superstructure decks.

Further in the present *Rules,* the general names for structural members as defined above (girder, stringer) are used interchangeably with traditional terms due to location and function of a given member (e.g. frame, longitudinal, beam, stringer, floor).

2.6 Other Definitions and Descriptions

Definitions and descriptions of not general character, appearing in particular chapters and sub-chapters are indicated and explained in those parts.

3 SHIP'S HULL TECHNICAL DOCUMENTATION

3.1 Technical Documentation of Ship's Hull under Construction

Prior to beginning the construction of the ship's hull, the documentation, specified in 1.4.2, is to be submitted to PRS for consideration and approval in the scope depending on the ship type, her equipment and outfitting. The PRS may extend the scope of the documentation upon examination of the ship technical specification and general arrangement plan.

3.2 Hull Documentation

.1 Data on the longitudinal, zone and local strength;
- basic theoretical data: body lines, hydrostatic curves,
- calculations of maximum still water bending moments and transverse forces acting in the hull sections,
- mass of light ship and its longitudinal distribution,
- intended load conditions and mass distribution of cargo and provisions on the ship*,
- minimum and maximum draught of the ship in service and corresponding trim,
- load on deck, hatch covers and inner bottom if different from those given in the Rules,
- maximum density of intended tank cargo or provisions,
- heights of air pipes, measured from the tank tops or from the decks above which these pipes are carried,
- mass of heavy machinery equipment and armaments,
- other local loads or forces which may affect the hull structure.

.2 Midship section with characteristic cross-sections, including main dimensions of the ship, full requested symbol of class, and other data such as speed, number of crew, etc.

.3 Longitudinal section with specified frame spacing, location of watertight bulkheads, pillars, superstructures and deckhouses.

.4 Shell expansion, including arrangement of girders, stiffeners, bulkheads, decks and platforms, as well as arrangement and dimensions of shell openings; the extent of bottom flat portion of the ship's fore part is to be shown in the drawing (if exists).

.5 Structural drawings of decks and platforms, including the arrangement and dimensions of the openings.

.6 Structural drawing of the double bottom.

.7 Structural drawings of longitudinal and transverse bulkheads, as well as the tank bulkheads, including the height of tank overflow and air pipes.

---

* Applicable for ships of $L > 65$ m.

.8 Structural drawings of the engine room region, including foundations of main engines and boilers, as well as the bottom structure under the foundations, tanks, pillars, strengthening, e.g. for upper fastening of the engine; type and rating of the engine should be given, the guidelines of the engine manufacturer concerning the foundation should be considered.

.9 Drawings of aft portion and stern indicating the distance from the propeller to stern and rudder.

.10 Drawings of forward portion and stem.

.11 Drawings of supports and exits of propeller shafts, suspension of rudder and fixed propeller nozzles.

.12 Structural drawings of superstructures and deckhouses.

.13 Structural drawings of armament system elements, rolling stabilizers and foundations for steering-propelling equipment.

.14 Tables of hull welding unless all data and dimensions concerning the welding are specified in the design drawings.

.15 Descriptions, drawings and test programs of innovative technological processes, design of structural joints and applied materials.

Moreover, the following technical documentations is to be submitted:

.16 For ships designated to carry vehicles:
- plan of the arrangement and securing of the carried vehicles, including the maximum axle load and forces in sockets and catches of the vehicle securing equipment,

.17 For ships carrying containers:
- arrangement plan of containers, including the data on their maximum mass and strength standard,
- fastening plan of containers, including sockets, stays and supports,
- drawings of supporting structures, including cell guide structures and adjacent structures of hull, as well as container sockets and other support with necessary reinforcements of hull structure,
- calculations of maximum forces and stresses in container supports, in adjoining hull structures, cell guides, lashing, etc.

.18 For ships mooring to other ships at sea:
- data on means attenuating hull impacts.

.19 For the ships performing loading operations at sea (including RAS, VERTREP supply):
- data of equipment applied for the purpose;
- data on loads occurring in this equipment and in accompanying installations.

.20 Other, not listed elements of equipment, which may affect the hull structure.

3.3 Hull Documentation of Ship under Alteration (Modernization)

Prior to beginning the ship alteration, the documentation of ship parts to be altered is to be submitted to PRS for consideration and approval.

3.4 Workshop Documentation of Ship

Upon approval of documentation listed in 3.2, the following workshop documentation is to be submitted to the PRS for consideration and acceptance:

– diagram of hull subdivision into sections and blocks, as well as the plan of assembling sequence,
– plan of non-destructive tests of welded joints,
– plan of hull tightness tests,
– drawings showing passage of pipelines, ventilation ducts and cables through hull plating, bottom, decks, bulkheads, girders, etc.,
– drawings of local strengthening under gear and machinery not shown in classification documentation,
– specification, drawings and test programme for innovatory engineering processes, solutions of structural nodes and materials applied,
– programme of mooring and sea trials.

4 SCOPE OF DIRECT CALCULATIONS

4.1 Calculations

Direct calculations of the hull loads (by ship hydromechanics method) and the hull response to the loads (usually by FEM – finite elements method) may be required in situations defined in Chapters B/14 to B/17, and in Section C.

For hulls of ships and other floating objects with features or dimensional proportions considered as non-typical, during appraisal of their technical documentation, direct calculations may also be required by PRS.

4.2 Presentation of Calculations Results

4.2.1 In the case where direct calculations of loads, or of structure response to the loads, have been applied, following information shall be submitted to PRS for consideration:

– description of applied calculation method and computer software (especially important in case of direct loads calculations);
– description of the structure's model for FEM calculations (parameters of structure elements, boundary conditions, loads);
– concise report on obtained calculations results).

4.3 Model Tests

In case of determining loads or the structure response to the loads on the basis of model tests, the following information shall be submitted to PRS:

– description of applied measurements method;
– description of the tested model;
– description of the apparatus applied;
– description of measuring apparatus calibration procedure;
– tests' input data (e.g. load in case of measurement of the structure response);
– report on measurements results (in the form of tables, diagrams, etc.);
– scaling of the results to actual object.

5 RANGE OF SURVEY

5.1 General principles for supervision over construction and surveys execution are given in *Part I – Classification Regulations.*

5.2 During construction, the whole hull structure is the object of supervision including:
- superstructures and deckhouses,
- machinery casings
- propeller shaft tunnels,
- main engines and boilers foundations,
- foundations for auxiliary engines and mechanisms, as well as for the equipment subject to supervision,
- armament foundations,
- shaft brackets, non-rotating nozzles,
- coamings, companionways and other structures limiting openings in the hull;
- movable ramps and platforms;
- casings of echo ranging stations, structural elements connected with special propulsion, propelling-steering devices.
- lifting appliances.

5.3 During construction, the structures listed in 5.2 shall be checked for:
- compliance with the approved technical documentation,
- fulfilling the requirements of the present part of the *Rules* not reflected in the technical documentation,
- fulfilling of applicable requirements of the *Part IX – Materials and Welding.*

5.4 Hull structures of all ships under construction shall be subjected to tightness and strength tests within the scope and methods given in the chapter 6.

6 THE HULL STRUCTURE TESTS

6.1 General

6.1.1 Definitions

Shop primer – is a thin coating applied after surface preparation and prior to fabrication as a protection against corrosion during fabrication.

Protective coating – is a final coating protecting the structure from corrosion.

Structural testing – is a hydrostatic test carried out to demonstrate the tightness of the tanks and the structural adequacy of the design. Where practical limitations prevail and hydrostatic testing is not feasible (for example when it is difficult, in practice, to apply the required head at the top of the tank), hydropneumatic testing may be carried out instead. When a hydropneumatic testing is performed, the conditions should simulate, as far as practicable, the actual loading of the tank.

Hydropneumatic testing – is a combination of hydrostatic and air testing, consisting in filling the tank with water up to its top and applying an additional air pressure. The value of the additional air pressure is at the discretion of the PRS, but is to be at least as defined in 6.2.2.

Leak testing – is an air or other medium test carried out to demonstrate the tightness of the structure.

Hose testing – is carried out using jet of water under adequate pressure, to demonstrate the tightness of structural items not subjected to hydrostatic or leak testing and to other components which contribute to the watertight or weathertight integrity of the hull.

6.1.2 Application

The requirements of Chapter 6 determine the testing conditions for:

– tanks,
– watertight, gastight or weathertight structures.

The purpose of these tests is to check the tightness and/or the strength of structural elements at time of ships construction and on the occasion of major repairs.

Tests are to be carried out in the presence of the PRS Surveyor at a stage sufficiently close to completion so that any subsequent work would not impair the strength and tightness of the structure.

For the general testing requirements, see items 6.3.

6.2 Testing Methods

6.2.1 Structural Testing

Structural testing may be carried out prior to application of the shop primer.

Structural testing may be carried out after the protective coating has been applied, provided that one of the following two conditions is satisfied:

a) all the welds are completed and carefully inspected visually to the satisfaction of the PRS Surveyor prior to the application of the protective coating,
b) leak testing is carried out prior to the application of the protective coating.

In absence of leak testing, protective coating should be applied after the structural testing of:

– all erection welds, both manual and automatic,
– all manual fillet weld connections on tank boundaries and manual penetration welds.

6.2.2 Leak Testing

Where leak testing is carried out, in accordance with Table 6.3, an air pressure of 15 kPa is to be applied during the test.

Prior to inspection, it is recommended that the air pressure in the tank is raised to 20 kPa and kept at this level for about 1 hour to reach a stabilized state, with a minimum number of personnel in the vicinity of the tank, and then lowered to the test pressure.

PRS may accept that the test is conducted after the pressure has reached a stabilized state at 20 kPa, without lowering the pressure, provided they are satisfied of the safety of the personnel involved in the test.

Welds are to be coated with an efficient indicating liquid, e.g. soap water.

A U-tube filled with water up to a height corresponding to the test pressure is to be fitted to avoid overpressure of the compartment tested and verify the test pressure. The U-tube should have a cross section larger than that of the pipe supplying air.

In addition, the test pressure is also to be verified by means of a master pressure gauge. PRS may accept alternative means which are considered to be equivalently reliable.

Leak testing is to be carried out, prior to the application of a protective coating, on all fillet weld connections on tank boundaries, penetrations and erection welds on tank boundaries with the exception of welds made by automatic processes. For other welds, leak testing may be carried out, after the protective coating has been applied, provided that these welds were carefully inspected visually to the satisfaction of the Surveyor.

Any other recognized method may be accepted to the satisfaction of the PRS Surveyor.

6.2.3 Hose Testing

When hose testing is required to verify the tightness of the structures, as defined in Table 6.3, the minimum pressure in the hose, at least equal to 0.2 MPa, is to be applied at a maximum distance of 1.5 m. The nozzle diameter is not to be less than 12 mm.

6.2.4 Hydropneumatic Testing

When hydropneumatic testing is performed, the same safety precautions as for leak testing (see 6.2.2) are to be adopted.

6.2.5 Gastightness Test

The test concerns closing appliances of the openings. Closing appliances shall meet following criterion: drop of pressure in compartments, in which the pressure has been raised to 1.5 kPa, shall not, after 10 min., exceed 0.13 kPa.

6.2.6 Other Testing Methods

Other testing methods may be accepted, at the discretion of PRS, based upon equivalency considerations.

6.3 General Testing Requirements

General requirements for testing are given in Table 6.3.

Table 6.3

Item No	Structure to be tested	Type of testing	Structural test pressure	Remarks:
1	2	3	4	5
1	Double bottom tanks	Structural testing[1]	The greater of the following: • head of water up to the top of overflow • head of water up to the margin line	Tank boundaries tested from at least one side
2	Double side tanks	Structural testing[1]	The greater of the following: • head of water up to the top of overflow • 2.4 m head of water above highest point of tank	Tank boundaries tested from at least one side
3	Tank bulk-heads, deep tanks	Structural testing[1]	The greater of the following[2] : • head of water up to the top of overflow • 2.4 m head of water above highest point of tank • setting pressure of the safety relief valves, where relevant	Tank boundaries tested from at least one side
	Fuel oil bunkers	Structural testing		
4	Fore peak and after peak used as tank	Structural testing	The greater of the following: • head of water up to the top of overflow • 2.4 m head of water above highest point of tank	Test of the after peak carried out after the stern tube has been fitted
	Fore peak not used as tank	Structural testing	0.3 m head of water above bulkhead deck; hose testing above this level	Head of water is to reach the level of the upper edge of the forepeak hatch coaming, where the height of the coaming is less than 0.3 m above bulkhead deck
	After peak not used as tank	Leak testing		

1	2	3	4	5
5	Cofferdams	Structural testing[3)]	The greater of the following: • head of water up to the top of overflow • 2.4 m head of water above highest point of tank	
6	Watertight bulkheads	Hose testing [4)]		The test shall be carried out in the most advanced stage of fitting out of the ship
7	Chain locker (if aft of collision bulkhead)	Structural testing	Head of water up to the top of chain locker	

Notes:

1) Leak or hydropneumatic testing (carried out according to 6.2.2) may be accepted, provided that at least one tank for each type is structurally tested, to be selected in connection with the approval of the design. In general, structural testing need not be repeated for subsequent vessels of a series of identical newbuildings. If the structural test reveals strength weakness or severe faults not detected by the leak test, all tanks are to be structurally tested.

2) Where applicable, the highest point of tank is to be measured to the deck and excluding hatch coamings.

3) Leak or hydropneumatic testing (carried out according to 6.2.2) may be accepted, at PRS discretion, considering the construction techniques and the welding procedures adopted.

4) When hose test cannot be performed without damaging outfitting (machinery, cables, switchboards, insulation, etc.) already installed, it may be replaced, at PRS discretion, by a careful visual inspection of all the crossings and welded joints; where necessary, dye penetrant test or ultrasonic leak test may be required.

B BASIC REQUIREMENTS

1 GENERAL

1.1 Requirements' structure

1.1.1 In this Section B the requirements necessary to obtain a basic class of ship are given, those requirements specified by the PRS ensure a minimum level of construction strength safety of the hull of the ship, within the operating load range – fixed and variable, including the sea loads on the calm water and wave loads, as well as loads of stocks, solid and liquid cargoes, the general loads of equipment and armaments, and other standard loads at the compartments of the ship – crew, service, etc.

1.1.2 In particular, section B shows the requirements for materials used in the hull construction and corrosion protection, requirements for specific design solutions of individual elements of the ship's hull (including the requirements for welded joints), requirements for the construction of the individual areas of the hull (bottom, sides, decks, etc.), principles of structure's scantling, design loads and strength criteria.

1.1.3 Requirements related to the adjustment of the ships hulls construction to the specific loads related to their function are given in section C of this *Part II*.

2 MATERIALS AND CORROSION PROTECTION

2.1 General

Materials intended for structures covered by the present Part of the *Rules* are to comply with the requirements of *Part IX – Materials and Welding* of the *Rules for the Classification and Construction of Sea-going Ships.*

2.2 Hull Structural Steels

2.2.1 Normal and Higher Strength Hull Structural Steel

2.2.1.1 Normal strength structural steel NS and higher strength structural steel HS 32, HS 36 and HS 40 are designated for use in the construction of the ship's hull.

2.2.1.2 The applied notations of hull structural steel, division into grades and corresponding values of yield point R_e (corresponding with the requirements of *Part IX – Materials and Welding*), as well as the values of material factors k are given in Table 2.2.1.2.

Table 2.2.1.2

Notation	Steel grade				R_e, [MPa]	k
NS	A	B	D	E	235	1.00
HS32	AH32	–	DH32	EH32	315	1.28
HS36	AH36	–	DH36	EH36	355	1.39
HS40	AH40	–	DH40	EH40	390	1.43

2.2.1.3 Materials applied in the strength members of hull structures of ships of $L_0 > 65$ m not subject to the effect of low temperatures (see 2.2.1.4) are not to be of lower grade than those given in Tables 2.2.1.3-1 and 2.2.1.3-2.

Table 2.2.1.3-1
Structural members groups and grades of material

Structural member	Members group/material grade	
	Within 0.4 L_0 amidships	Outside 0.4 L_0 amidships
Secondary: Deck plating exposed to weather, in general Side plating	I	A/AH
Primary: Bottom plating, including keel plate Strength deck plating [1)] Continuous longitudinal members above strength deck, Upper strake in longitudinal bulkhead plating	II	A/AH
Special: Sheer strake at strength deck Stringer plate in strength deck Deck strake at longitudinal bulkhead Bilge strake [2)]	III	II (I outside 0.6L_0)

Notes:
1) Plating at corners of large hatch openings is to be specially considered. Class III or grade E/EH is to be applied in positions where high local stresses may occur.
2) May be of class II in ships with a double bottom over the full breadth and with length less than 150 metres.

The material grade requirements for hull members of each class depending on thickness are defined in Table 2.2.1.3-2.

For strength members not mentioned in Table 2.2.1.3-1, as well as for structural elements of the ships of length $L_0 < 40$m, grade A/AH may generally be used. Single strakes required to be of class III or of grade E/EH are, within 0.4 L_0 amidships, to have breadths not less than $800 + 5L_0$, [mm], however, the breadths need not be greater than 1800 mm. The steel grade is to correspond to the as-built plate thickness when this is greater than required by this *Part* of the *Rules*.

Structural groups and grades of materials applied for the hulls of ships with length 40 m $\leq L_o \leq$ 65 m, as well as for heavy loaded areas of hull structures of ships with length $L_o < 40$ m (e.g. in area of cranes, armament, etc.) are subject of separate PRS consideration.

Materials for stern frames plating, rudders, rudder and shaft brackets should, in general, be of category corresponding to at least group II of the structural members, irrespective of the length of the ship. In case of rudder and rudder blade exposed to stresses concentration (e.g. in area of a lower support of semi-spade rudders or in an upper part of spade rudders) material corresponding to III group of structural members shall be applied.

Table 2.2.1.3–2
Material grade requirements for classes I, II and III

Class	I		II		III	
Thickness, in mm	NS	HS	NS	HS	NS	HS
t ≤ 15	A	AH	A	AH	A	AH
15 < t ≤ 20	A	AH	A	AH	B	AH
20 < t ≤ 25	A	AH	B	AH	D	AH
25 < t ≤ 30	A	AH	D	AH	D	AH
30 < t ≤ 35	B	AH	D	DH	E	EH
35 < t ≤ 40	B	AH	D	DH	E	EH
40 < t ≤ 50	D	DH	E	EH	E	EH

2.2.1.4 For ships intended to operate in areas with low air temperatures (–20 °C and below), the materials in exposed structures are to be selected based on the design temperature t_p, to be taken as defined in 2.2.4.

Materials for the strength members above the lowest ballast water line (BWL) exposed to air are not to be of lower grades than those given in Table 2.2.1.4-1, depending on the length L_0 as given in 2.2.1.3.

Table 2.2.1.4-1
Application of material classes and grades-structures exposed to low temperatures

Structural member	Material class	
	Within 0.4 L_0 amidships	Outside 0.4 L_0 amidships
Secondary: Deck plating exposed to weather, in general Side plating above BWL Transverse bulkheads above BWL	I	I
Primary: Strength deck plating [1] Continuous longitudinal members above strength deck, excluding longitudinal hatch coamings Longitudinal bulkhead above BWL	II	I
Special: Sheer strake at strength deck Stringer plate in strength deck Deck strake at longitudinal bulkhead Continuous longitudinal hatch coamings [2]	III	II

Notes:

1) Plating at corners of large hatch openings is to be specially considered. Class III or grade E/EH to be applied in positions where high local stresses may occur.
2) Not to be less than grade D/DH.

Table 2.2.1.4-2
Material grade requirements for classes I, II and III at low temperatures

Class I

Plate thickness, in mm	–20/–25°C		–26/–35°C		–36/–45°C		–46/–55°C	
	NS	HS	NS	HS	NS	HS	NS	HS
t ≤ 10	A	AH	B	AH	D	DH	D	DH
10 < t ≤ 15	B	AH	D	DH	D	DH	D	DH
15 < t ≤ 20	B	AH	D	DH	D	DH	E	EH
20 < t ≤ 25	D	DH	D	DH	D	DH	E	EH
25 < t ≤ 30	D	DH	D	DH	E	EH	E	EH
30 < t ≤ 35	D	DH	D	DH	E	EH	E	EH

∅ = Not applicable

Class II

Plate thickness, in mm	–20/–25°C		–26/–35°C		–36/–45°C		–46/–55°C	
	NS	HS	NS	HS	NS	HS	NS	HS
t ≤ 10	B	AH	D	DH	D	DH	D	DH
10 < t ≤ 20	D	DH	D	DH	E	EH	E	EH
20 < t ≤ 30	D	DH	E	EH	E	EH	∅	FH
30 < t ≤ 40	E	EH	E	EH	∅	FH	∅	FH

∅ = Not applicable

Class III

Plate thickness, in mm	–20/–25°C NS	HS	–26/–35°C NS	HS	–36/–45°C NS	HS	–46/–55°C NS	HS
t ≤ 10	D	DH	D	DH	E	EH	E	EH
10 < t ≤ 20	D	DH	E	EH	E	EH	∅	FH
20 < t ≤ 25	E	EH	E	EH	∅	FH	∅	FH
25 < t ≤ 30	E	EH	E	EH	∅	FH	∅	FH
30 < t ≤ 35	E	EH	E	EH	∅	FH	∅	FH

∅ = Not applicable

For non-exposed structures and structures below the lowest ballast water line the Tables 2.2.1.3-1 and 2.2.1.3-2 are to be used.

The material grade requirements for hull members of each class depending on thickness, design temperature and group of joints are defined in Table 2.2.1.4-2. The requirements do not depend on the ship's length L_0. For design temperatures t_p < –55 °C, materials are to be specially considered by the PRS.

Single strakes required to be of class III or of grade E/EH or FH are to have breadths not less than 800 + 5L_0, [mm], however, the breadths need not be greater than 1800 mm.

Plating materials for sternframes, rudder horns, rudders and shaft brackets are not to be of lower grades than those given in 2.2.1.3.

2.2.2 Steel with Specified Through Thickness Properties

2.2.2.1 Where a plate type structural element of the thickness 15 mm and more is exposed to considerable tensile stress perpendicular to its plane and no solution preventing delamination has been provided, this element is to be made of Z-type steel.

2.2.2.2 Steel for plates of the thickness 15 mm and more, subjected to tensile load perpendicular to their surface, is to comply with the requirements for steel Z given in Chapter 5 of *Part IX – Materials and Welding*.

Unless agreed otherwise with PRS, these plates are to be made of E, EH or FH steel grades.

2.2.3 Clad Steel

Where clad steel is used, its mechanical properties are to be not worse than those required for steel grades specified in Tables 2.2.1.3-1 and 2.2.1.3-2. Hull structural steel is to be considered as the base material.

2.2.4 Design Temperature of Structures

2.2.4.1 As the design temperature tp the lowest mean daily average air temperature in the area of operation is to be taken.

Lowest: Lowest during a year.

Mean: Statistical mean over observation period (at least 20 years).

Average: Average during one day and night.

For seasonally restricted service, the lowest value within the period of operation applies.

Fig. 2.2.4.1 illustrates the temperature definition.

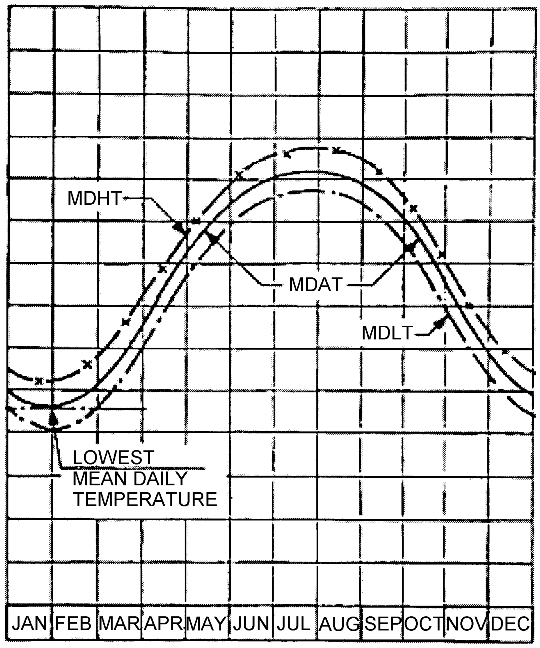


Fig. 2.2.4.1

MDHT = Mean Daily High (or maximum) Temperature
MDAT = Mean Daily Average Temperature.
MDLT = Mean Daily Low (or minimum) Temperature.

2.2.4.2 For ships with L1A or L1 ice strengthening mark in the symbol of class, the assumed value of temperature t_p is not to be greater than –20° C.

The design temperature of structures located inside refrigerated spaces is to be taken equal to the lowest air temperature t_a inside the spaces. The design temperature of structures forming boundaries of refrigerated spaces is to be equal to:

- the lowest temperature in the refrigerated space if the structure has not been covered with insulation on the side of this space,
- the lowest temperature of the adjacent space if the structure has been covered with insulation in the refrigerated space and has not been insulated on the other side,
- the mean lowest temperature of the adjacent spaces if the structure has been covered with insulation on both sides.

In well-grounded cases, the values of design temperatures may be increased.

2.3 Other Structural Materials

2.3.1 Aluminium Alloys

2.3.1.1 Aluminium alloys of grade according to *Part IX – Materials and Welding* may be applied to construction of:
– hull structure of length $L_0 < 40$ m,
– superstructures and deckhouses.

2.3.1.2 The strength of aluminium structure is not to be worse than that required for steel structures.

2.3.1.3 The material factor k for aluminium alloys is to be determined from the following formula:

$$k = \frac{R_e}{235} \qquad (2.3.1.3)$$

where R_e value, characteristic for soft (re-crystalized or hot rolled) condition of the aluminium alloy, is not to be taken greater than 0.7 R_m (R_m – tensile strength).

Where aluminium alloys delivered in semi-hard or quarter-hard condition are to be used for welded structures, yield stress is to be agreed with PRS in each particular case.

2.3.2 Alternative Materials

The application of alternative materials for ship structure will be specially considered by PRS in each particular case.

2.4 Corrosion Protection

2.4.1 All salt water ballast tanks having boundaries formed by the hull envelope are to have an efficient protective coating – epoxy or equivalent – applied in accordance with the manufacturer's recommendations. The coating should preferably be of a light colour.

In grounded cases, sacrificial anodes shall also be used.

It is recommended that all structural elements of a steel hull of the ship are covered with a corrosion protective coating.

At the request of the owner, after special consideration by PRS, the corrosion additions required in 2.5 may be reduced or omitted on condition that the effective corrosion protection of the structure is provided. In this case, the ship may be affixed with the additional mark **PAC** in the symbol of class.

2.4.2 In tanks intended for the carriage of water ballast, the thickness of structural elements is to be increased by corrosion additions defined in 2.5.

2.4.3 Protection against corrosion in tanks for aviation and special fuel, and other aggressive – due to corrosion – liquids shall be separately considered by PRS.

2.4.4 The requirements concerning corrosion protection coating and cathodic protection are given in *Publication No. 40/P – Non-metallic Materials*.

2.5 Corrosion Additions

2.5.1 Paragraphs 2.5.2 to 2.5.6 concern structural elements of the ship's steel hulls.

2.5.2 In the case of a structure made of aluminium alloys corrosion additions are not required.

2.5.3 The thickness of plating of vertical and horizontal bulkheads forming boundaries of the tanks is to be increased by corrosion addition t_k determined from the formula:

$$t_k = t_w + t_z, \quad \text{[mm]} \qquad (2.5.3)$$

t_w – corrosion addition determined according to 2.5.6 for the inner side of plating, [mm];
t_z – corrosion addition determined according to 2.5.6 for the outer side of the plating, according to the designation of the adjacent space, [mm].

2.5.4 The thickness of face plates, webs and brackets of stiffeners and girders, placed inside the ballast tanks, is to be increased by corrosion addition t_k determined from the formula:

$$t_k = 2\,t_w, \quad \text{[mm].} \qquad (2.5.4\text{-}1)$$

Where stiffeners or girders of the tank bulkhead are at its outer side, the corrosion addition t_k is to be determined from the formula:

$$t_k = 2\,t_z, \quad \text{[mm]} \qquad (2.5.4\text{-}2)$$

t_w and t_z – as in 2.5.3.

2.5.5 For horizontal webs or face plates of stiffeners or girders, the corrosion addition is to be additionally increased by 0.5 mm.

2.5.6 Corrosion additions t_w and t_z depend on area (A, B) of the tank in which the considered structural element is installed.

Where the upper side of tank or cargo hold is closed by the weather deck, then A area of this tank or cargo hold is the area extending vertically from the weather deck to the level 1.5 m below this deck. All other areas of tanks and cargo holds are B areas.

2.5.7 Depending on the type of agent acting on the considered side of the structural element, the corrosion additions t_w or t_z for A area are as follows:

1.5 mm – for water ballast,
0.0 mm – for (external) outboard water or air.

The corrosion additions t_w or t_z for B area are equal to half of the values provided for A area.

3 STRUCTURAL DETAILS

3.1 General

Methods of determining the geometrical and strength parameters of the hull structure members, specified in the present Chapter, may be applied to the strength analysis of members unless stated otherwise in other Chapters of the present Part of the *Rules*.

3.1.1 Rounding off the Scantlings

3.1.1.1 Scantlings are to be rounded off to the nearest greater standard value. It is allowed to round off the plate thickness required for structural members to the nearest lower standard value within a margin of 0.25 mm.

3.1.1.2 When standard rolled sections are applied, it is allowed to round off the required values of section modulus, moment of inertia and cross-sectional area to the nearest lower standard value but by not more, however, than 3% of the required value.

3.2 Modelling of Structural Members

3.2.1 Span of Girders and Stiffeners

3.2.1.1 The design span l of girders and stiffeners is to be determined in the way shown in Fig. 3.2.1.1. It is assumed that the brackets are adequately supported by the structure, to which they are attached. In particular cases estimation of the span l may be different. The span l is to be measured as the length of the chord joining the ends of the support points.

3.2.2 Effective Flange

3.2.2.1 The cross-sectional area of effective plate flange for stiffener or simple girder is to be determined from the following formula:

$$A_p = 10 b_e t , \quad [\text{cm}^2] \qquad (3.2.2.1)$$

t – mean thickness of the effective flange, [mm];
b_e – effective flange breadth, according to 3.2.2.2, [m].

Continuous stiffeners, parallel to the web of girder in question and located within b_e width, may be included with 50% of their cross-sectional area in the effective plate flange area of the girder.

The effective plate flange area is not to be less than the sectional area of the free flange.

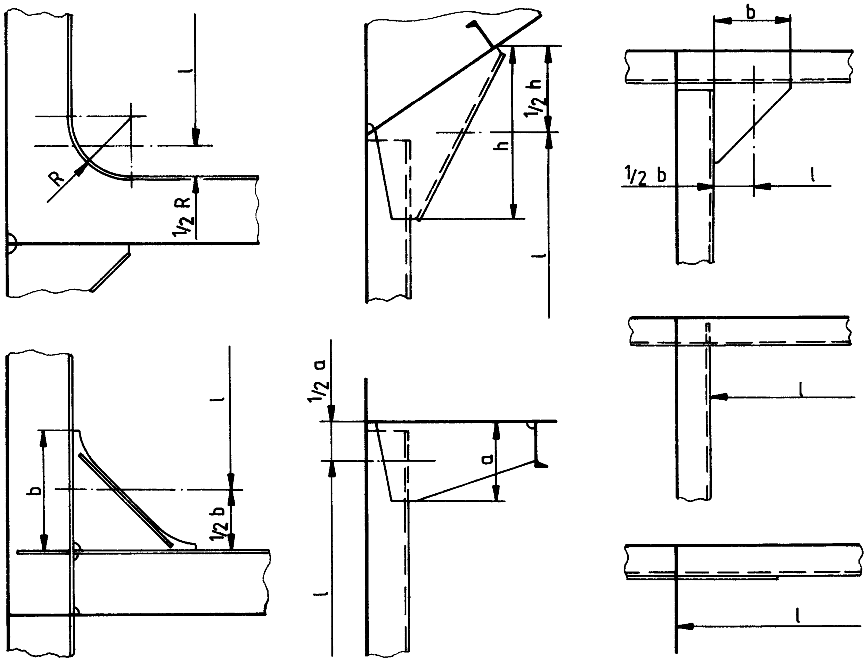


Fig. 3.2.1.1 Determining the span of structural members

3.2.2.2 The effective flange width of stiffener may be taken equal to the lesser of the two values determined by the following formulae:

$$b_e = \frac{1}{6} l, \quad [\text{m}] \qquad (3.2.2.2\text{-}1)$$

$$b_e = 0.5(s_1 + s_2), \quad [\text{m}] \qquad (3.2.2.2\text{-}2)$$

l – stiffener span, [m];
s_1, s_2 – distances from stiffener in question to the adjacent stiffeners fitted at its both sides, [m].

3.2.2.3 The effective flange width of simple girder is to be determined by the formula:

$$b_e = K b, \quad [\text{m}] \qquad (3.2.2.3)$$

b = 0.5 (b_1 +b_2), [m];
b_1, b_2 – distances from girder in question to the nearest girders of the same type fitted at its both sides, [m];
K – coefficient, determined from Table 3.2.2.3, depending on the span l_z of the girder, as well as on number n of evenly spaced perpendicular stiffeners supported by the girder in question;
$l_z = l$ – for simply supported girder at both its ends, [m];
$l_z = 0.6\, l$ – for girder fixed at both its ends, [m].

Table 3.2.2.3
Values of *K*

Number of stiffeners n	l_z / b ratio						
	1	2	3	4	5	6	7 and more
≥ 6	0.38	0.62	0.79	0.88	0.94	0.98	1
≤ 3	0.21	0.40	0.53	0.64	0.72	0.78	0.80

For intermediate values of l_z / b ratio, coefficient K may be obtained by linear interpolation.

3.2.2.4 In case of curved stiffeners' face plates or girders the effective sectional area A_e of the face plate is to be determined from the formula:

$$A_e = c \cdot b_m \cdot t_m \text{ , [mm}^2\text{]} \qquad (3.2.2.4\text{-}1)$$

where:
b_m – breadth of a face bar, [mm],
t_m – thickness of a face bar, [mm],
c – numerical coefficient determined from the formula (in formula 3.2.2.4-1 $c \leq 1$ shall be assumed):

$$c = c_1 \frac{\sqrt{r \cdot t_m}}{b} \qquad (3.2.2.4\text{-}2)$$

r – radius of a face plate curvature, [mm];
$b = b_m$, [mm] – for asymmetrical face plates;
$b = 0.5(b_m - t_s)$, [mm] – for symmetrical face plates;
t_c – thickness of a web, [mm],
c_1 – coefficient of values given in Table 3.2.2.4, depending on argument:

$$\beta = \frac{1.29 \cdot b}{\sqrt{r \cdot t_m}} \qquad (3.2.2.4\text{-}3)$$

Note: formula 3.2.2.4-1 shall also be applied when determining effective section area of curved plating supported by the stiffener, assuming $b_m = s = b$ (s – stiffeners spacing) and $t_m = t$ (t – plating thickness).

Table 3.2.2.4
Values of coefficient c_1

β	0.2	0.25	0.3	0.4	0.45	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	≥ 1.6
c_1	3.21	2.57	2.14	1.84	1.61	1.43	1.29	1.08	0.94	0.83	0.76	0.70	0.60	0.59

Note: for the intermediate values of β, coefficient c_1 shall be determined by linear interpolation.

3.2.2.5 Effective section area A_e curved face plates for girders supported by brackets welded to webs, or effective section area of curved plating supported by girders and stiffeners in direction transverse to girders (Fig. 3.2.2.5) shall be calculated from the formula:

$$A_e = \frac{3r\,t_m + c \cdot s^2}{3r\,t_m + s^2} \cdot t_m \cdot b_m\,, \quad [\text{mm}^2] \qquad (3.2.2.5)$$

where:

r, t_m, c – as in 3.2.2.4; calculating effective area A_e of curved plating strake constituting girder's face plate in formula 3.2.2.5 $b_m = b_1$, $t_m = t$ (b_1, t – see Fig. 3.2.2.5) shall be assumed;

s – spacing of plating stiffeners or brackets supporting the web, [mm] (Fig. 3.2.2.5)

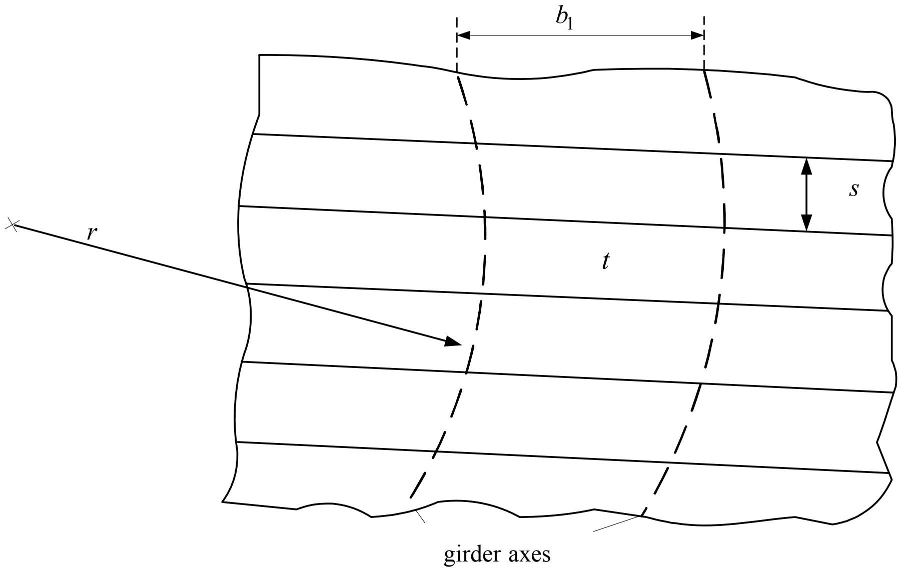


Fig. 3.2.2.5

3.2.2.6 Effective flange width b_e of corrugated bulkhead girders perpendicular to the corrugations shall be taken equal respectively to 15 t – for trapezoidal corrugations and 20 t for undulated corrugations, respectively or 0.1 b for both cases, whichever value is the lesser.

b means the effective flange width, calculated in accordance with paragraph 3.2.2.3, whereas t means the corrugated bulkhead plating thickness.

3.2.2.7 Effective flange width b_e of hatchway coaming shall be taken equal to 1/12 of its span. The assumed value of b_e shall not be greater than half the distance from hatchway coaming to the ship's side for longitudinal coamings or half the distance between the coaming and the nearest transverse bulkhead for transverse coamings.

3.2.3 Effective Sectional Area of Web

The effective cross-sectional area of simple girders is to be determined by the formula:

$$A_s = 0.01\,h_s t_s\,, \quad [\text{cm}^2] \qquad (3.2.3)$$

t_s – web thickness, [mm];
h_s – net web height, [mm].

Net web height h_s is to be determined by deduction of cut-outs and openings in the cross-section considered. If the edge of web opening is located at a distance less than $h/3$ from the cross section considered, h_s is to be taken as the smaller of two values: h_s and $(h_1 + h_2)$, shown in Fig. 3.2.3.

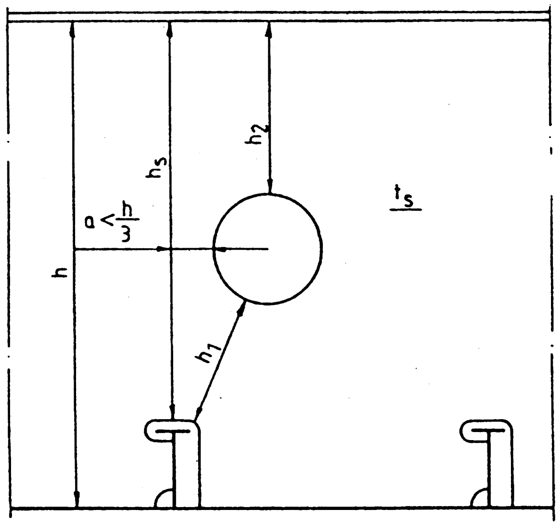


Fig. 3.2.3 Determining the net web height

3.2.4 Section Moduli and Moments of Inertia of Stiffeners and Girders

Section moduli and moments of inertia of cross-sections of stiffeners and girders required by the present *Part II* of *the Rules* refer to the neutral axis parallel to the plating.

Where the web of structural member is not perpendicular to the plating, the value of the section modulus about the axis parallel to the plating for $\alpha < 15°$ (α – angle between the plane perpendicular to the plating and the web plane) may be determined approximately by multiplying the section modulus of the stiffeners perpendicular to the plating by cos α.

Unless otherwise stated, the effective flange taken for the calculation is to be determined according to 3.2.2.

Note: The section modulus of corrugated bulkhead members may be calculated from the following approximate relations:

– for corrugated bulkhead member of trapezoidal cross-section and width equal to s_1:

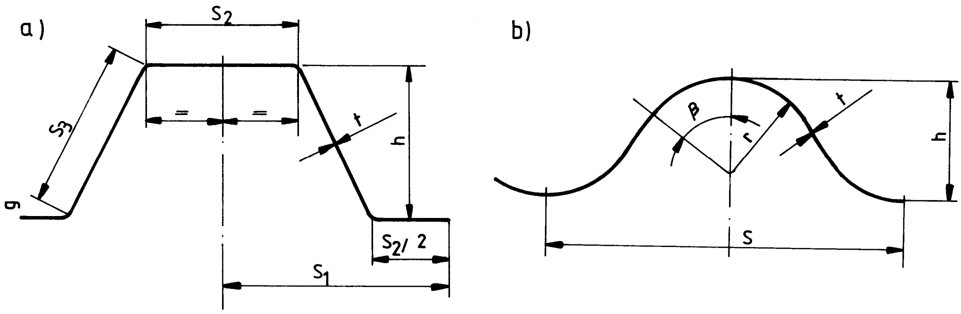
$$W = \frac{h\,t}{2}\left(s_2 + \frac{s_3}{3}\right), \quad [\text{cm}^3] \qquad (3.2.4\text{-}1)$$

h, t – see Fig. 3.2.4 a, [mm];
s_2, s_3 – see Fig. 3.2.4 a, [m];

– for corrugated bulkhead member of undulated cross-section and width equal to *s*:

$$W = c\,t\,r^2, \quad [\text{cm}^3]$$
$$s = 4\,r\sin\beta \qquad (3.2.4\text{-}2)$$
$$c = 2\frac{\beta + 2\beta\cos^2\beta - 1.5\sin 2\beta}{1-\cos\beta}$$

t, *r*, *s* – see Fig. 3.2.4 b, [cm];
β – see Fig. 3.2.4 b, [radians].



$$h = 2\,r\left(1-\cos\beta\right)$$

Fig. 3.2.4

3.3 Details of Welded Structures

3.3.1 Arrangement of Welded Joints

Local concentration of welds, crossing of welds at an acute angle, as well as close location of parallel butts or fillet welds and parallel butt welds are to be avoided. The distances between parallel welded joints, irrespective of their direction, are to be not less than:

– 200 mm between butt welds,
– 75 mm between a fillet weld and a butt weld,
– 50 mm between a fillet and a butt weld over a length not exceeding 2 m.

The angle between butt welds is not to be less than 60° (see Fig. 3.3.1).

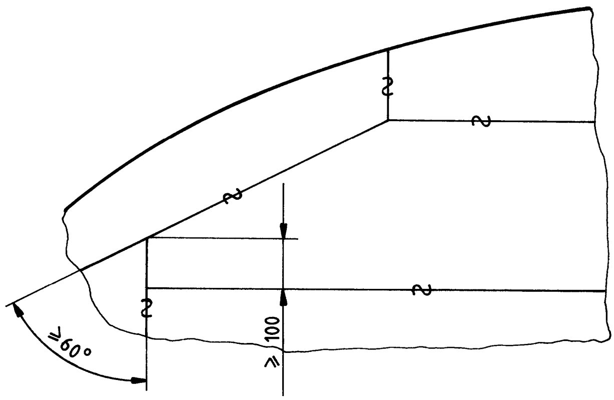


Fig. 3.3.1 Arrangement of welded joints

The distance of joints (butts) of shell and deck plates from bulkheads, decks, inner bottom plating, girders, etc., arranged parallel to the joints, is not to be less than 5 *t* (*t* – plate thickness) or 100 mm, whichever is the greater. For assembly joints (butts), this distance is not to be less than 200 mm.

3.3.2 Joints of Face Plates

Face plate joints of crossing girders subjected to dynamic loads and girders of strength decks and single bottom amidships, as well as other highly loaded girders are to be made with smooth transition by means of diamond plates of thickness not less than the thickness of joined girder face plates (see Fig. 3.3.2).

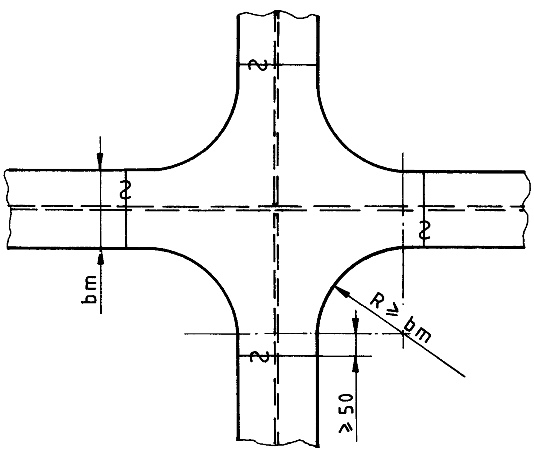


Fig. 3.3.2 Joints of girder face plates

3.4 Continuity of Structure

3.4.1 General Requirements

Structural continuity is to be maintained in the hull structure. Any changes in the shape of sections and in the member thickness are to be smooth.

3.4.2 Continuity of Longitudinal Members

3.4.2.1 Any changes in the scantling of sections and in longitudinal member plate thickness along the hull are to be smooth. The arrangement and scantlings of members in the strength deck, bottom, sides and longitudinal bulkheads in areas of change of the strength properties of steel are to be kept unchanged.

3.4.2.2 The distance between the end of the stiffener and perpendicular, to the stiffener, web of girder or other stiffener is to be as small as practicable and is not to exceed 4 t or 60 mm, whichever is the lesser (t – plating thickness, [mm]).

3.4.3 Connections

It is recommended that rounded brackets are fitted where girders are connected to each other. The web of a girder is to be stiffened at the ends of brackets.

3.5 Openings in Structural Members

3.5.1 General Requirements

3.5.1.1 The total height of openings (lightening holes, single cut-outs in way of members, etc.) in one cross-section of a member is not to exceed 0.4 of its depth. In justified cases, this value may be increased in the centre of span to no more than 0.6 of the member depth.

3.5.1.2 The distance between edges of all openings in girder and edges of single slots in way of stiffeners is not to be less than the depth of these stiffeners.

3.5.1.3 The holes in webs of stiffeners and girders are not to be arranged at a distance less than the web depth from the toe of end bracket.

3.5.1.4 Openings in member webs for free flow of liquid to the sucking terminals and for free flow of air to the air pipes are to be arranged inside the tanks. These openings are to be as close to the bottom and deck as practicable. It is recommended that openings in bottom and deck longitudinals are elliptical and are located at a distance not less than 20 mm from the bottom and deck plating. The height of the openings is to be not greater than 0.25 of the web height and is not to exceed 75 mm. The length of openings is not to exceed 150 mm.

3.5.1.5 Corners of any openings in members are to be rounded with a radius of curvature not less than twice the plate thickness.

3.5.1.6 Openings in side shell, longitudinal bulkheads and longitudinal girders are to be located not less than twice the opening breadth below strength deck or termination of rounded deck corners.

3.5.1.7 Small openings are generally to be kept well clear of other openings in longitudinal strength members. Non-reinforced edges of small openings are to be located at a transverse distance not less than four times the opening breadth from the edge of any other opening.

3.5.1.8 Openings in longitudinals are to be of elliptical shape and are to be kept clear of the connecting welds on these longitudinals.

3.5.2 Reinforcement of Opening Edges

3.5.2.1 The requirements given below are applicable to openings in strength deck and outer bottom in the middle portion of ship's hull within $-0.3\ L_0 < x < 0.3\ L_0$, and for ships with large hatchway openings within the total cargo hold region. The requirements concerning the shape and strengthening in way of hatch corners are given in 8.5.

3.5.2.2 Circular openings with diameter greater than 0.325 m are to have edge reinforcement. The cross-sectional area of edge reinforcements is not to be less than:

$$A_o = 2.5\,d\,t\,, \quad [\text{cm}^2] \qquad (3.5.2.2)$$

d – diameter of opening, [m];
t – plate thickness, [mm].

3.5.2.3 Elliptical openings with breadth greater than 0.5 m are to have edge reinforcement if their length/breadth ratio is less than 2. The reinforcement is to be as required above for circular openings where d is to be taken equal to the opening breadth.

3.5.2.4 Rectangular or approximately rectangular openings are to have edge reinforcement according to 3.5.2.2 where d is to be taken equal to the opening breadth. Corners of such openings are to comply with the following requirements:

– for corners of circular shape, the radius is not to be less than:

$$R = 0.2\,b\,, \quad [\text{m}] \qquad (3.5.2.4)$$

b – breadth of opening, $b \geq 0.4$ m is to be taken;

– for corners of streamlined shape, the transverse extension of the curvature (perpendicular to ship center line) is not to be less than 0.15 b.

3.6 Girder Construction

3.6.1 General Requirements

3.6.1.1 The requirements of the present sub-chapter refer to the girders made as T-sections or I-sections.

3.6.1.2 Depth h and thickness t_s of web of girders (as well as of transverse frames and longitudinal stiffeners welded of separate webs and face plates), as well as their cross-sectional areas are covered by the requirements contained in particular Chapters of the present *Part II* of the *Rules*.

3.6.1.3 The girder web plate and flange are to be stiffened by tripping brackets according to 3.6.4. Stiffeners parallel or perpendicular to the flanges may also be required, according to 3.6.3, unless otherwise stated in the present *Part II* of the *Rules*.

3.6.2 Girder Flanges

3.6.2.1 Unsupported breadth of girder flange b, measured from the web, is not to be greater than:

$$b = \frac{200\,t_m}{\sqrt{R_e}}, \quad \text{[mm]} \qquad (3.6.2.1)$$

t_m – flange thickness, [mm];
c – 1.0 for steel
c – 0.58 for aluminium alloys.

3.6.2.2 Flange thickness is not to exceed triple thickness of the web.

3.6.3 Girder Stiffeners

3.6.3.1 Girder webs are to meet the buckling strength criteria given in 13.6.4.2.

Where the ratio of girder web height h to its thickness t_s is greater than $890/\sqrt{R_e}\,c$ (c=1.0 for steel; c=0.58 for aluminium alloys), then the girder web is to be stiffened irrespective of supporting by tripping brackets arranged according to 3.6.4.

The girder web may be stiffened by means of stiffeners perpendicular to the flange and tripping brackets (see Fig. 3.6.3.1a) or by stiffeners parallel to the flange and tripping brackets (see Fig. 3.6.3.1b).

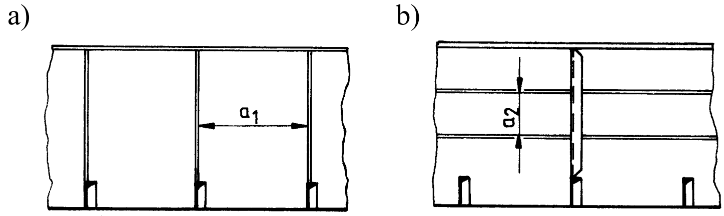


Fig. 3.6.3.1 Methods of stiffening the girder web

3.6.3.2 Stiffeners of girder webs shown in Fig. 3.6.3.1 are to meet the requirements of 13.5.3 regarding buckling strength of stiffeners, for design stress values determined according to 13.3.2.7 and 13..3.2.10.

3.6.3.3 Framing or strengthening of openings in webs in the way defined in 13.4.3.10 or 13.4.3.11 may be required for the purpose of meeting the girder web buckling strength criteria.

3.6.4 Tripping Brackets

3.6.4.1 Girder tripping brackets are to be fitted as required in para. 3.6.4.2, irrespective of stiffeners referred to in 3.6.3. Additionally, tripping brackets are to be fitted at the end parts of the girder (near toe of brackets, near rounded corner of girder frames) and in line with any cross ties.

3.6.4.2 In no case the spacing of tripping brackets is to exceed 3 m or 15 b_m (b_m – full breadth of girder flange), whichever value is the lesser.

3.6.4.3 The thickness of tripping brackets is not to be less than the girder web thickness.

3.6.4.4 Tripping brackets are to be extended to the flange and welded to it if the flange breadth measured from the web to the free edge exceeds 150 mm. Where the breadth of a flange symmetrical to the girder web exceeds 400 mm, a small bracket is to be fitted on a flange on the opposite side of tripping bracket.

3.6.4.5 The breadth of tripping bracket measured at its toe is not to be less than half of its depth.

3.6.4.6 Where the length of free edge l_k of tripping bracket exceeds 60 t_{wp} (t_{wp} – thickness of tripping bracket, [mm]; c = 1.0 for steel; c = 0.58 for aluminium alloys), a flange or face plate is to be applied along this free edge. The cross-sectional area of flange or face plate is not to be less than:

$$f_k = 0.01 l_k, \quad [\text{cm}^2] \tag{3.6.4.6}$$

l_k – length of free edge, [mm].

4 JOINTS OF STRUCTURAL ELEMENTS

4.1 General

4.1.1 The requirements concerning types and size of welds, welded and steel-aluminium joints are specified in this Chapter.

4.1.2 Irrespective of the requirements set forth in this Chapter, the requirements concerning welding materials, welding methods, welders qualifications, quality control of welds and protection against atmospheric effects during welding, specified in *Part IX – Materials and Welding*, are to be complied with.

4.1.3 The welding sequence is to be so designed as to ensure possibly free material shrinkage.

4.2 Types and Size of Welds

4.2.1 Butt Joints

4.2.1.1 The edges of butt-welded plates of equal thickness are to be prepared as shown in Fig. 4.2.1.1.

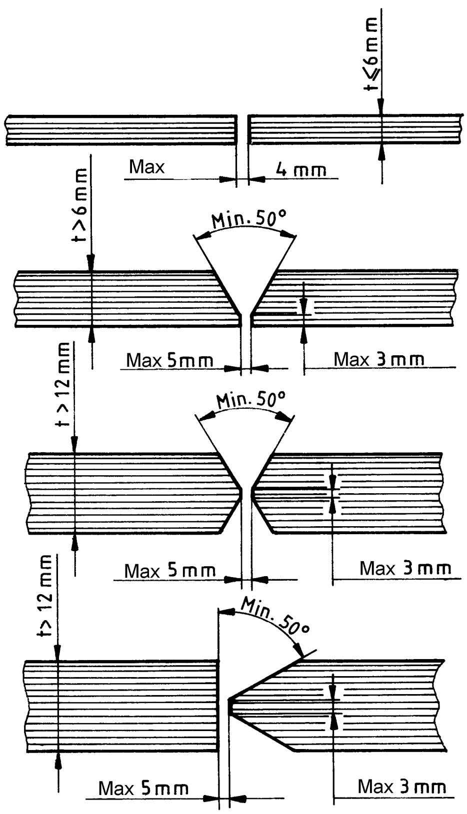


Fig. 4.2.1.1 Edge preparation for manual butt welding

4.2.1.2 Where two butt-welded plates are different in thickness by more than 3 mm, the thickness of the thicker plate is to be reduced by bevelling not exceeding 1 : 3. Upon reduction of the thickness, the edges are to be prepared for welding like the plates of equal thickness (see Fig. 4.2.1.2).

4.2.1.3 All types of butt welds are to be, in general, double side welded joints. Prior to welding the other side, the weld root is to be cut out to clean metal. One side welding may be applied, upon special consideration by PRS, for low loaded structures or the structures where sealing weld is impossible.

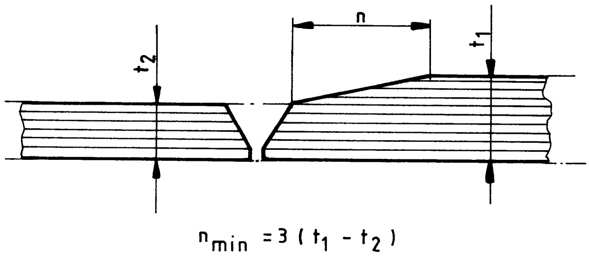


Fig. 4.2.1.2 Edge preparation for welding plates of different thickness

4.2.2 Lap and Slot Welds

4.2.2.1 Examples of typical lap and slot welds are shown in Fig. 4.2.2.1.

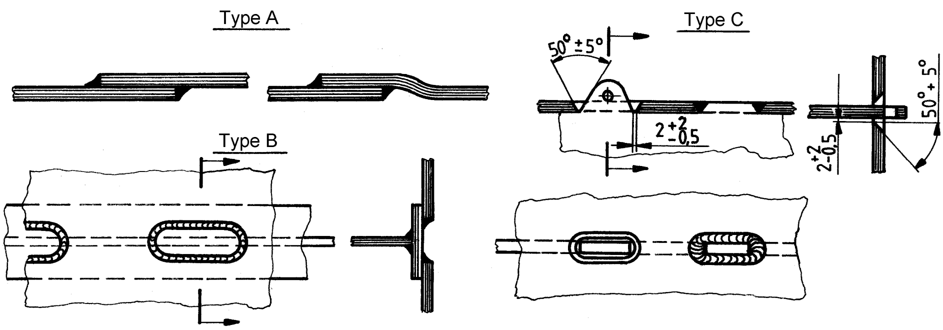


Fig. 4.2.2.1 Lap and slot welds

4.2.2.2 Type A (lap weld) may be used for welding brackets to ends of stiffeners for normally loaded joints except the areas where increased vibration may be expected.

4.2.2.3 B type (slot weld) and C type (pin slot weld) may be used for welding the plating to inner stiffeners – where fillet welding of T-joint is impossible. Dimensions and spacings of slots will be separately considered by PRS.

4.2.2.4 Lap joints are to be made with continuous weld at the perimeter, with $\alpha = 0.4$ – see 4.2.3.1. The overlap width is to be not less than:

$$b = 2s + 25, \quad \text{[mm]}$$

and in no case less than 50 mm (s – thickness of the thinner component, [mm]).

4.2.3 Fillet Welds

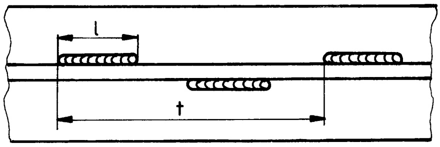
4.2.3.1 The design thickness *a* of fillet welds (see Fig. 4.2.3.1) is not to be less than the value determined from the following formula:

$$a = \alpha \beta s, \quad \text{[mm]} \tag{4.2.3.1}$$

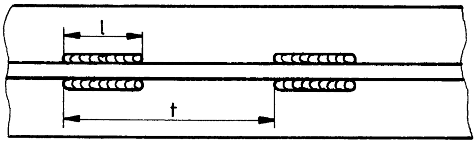
α – weld strength coefficient according to Table 4.2.3.1-1;
β – coefficient determined from Table 4.2.3.1-2;
s – thickness of thinner component, [mm].

The fillet weld thickness *a* is to be also not less than:

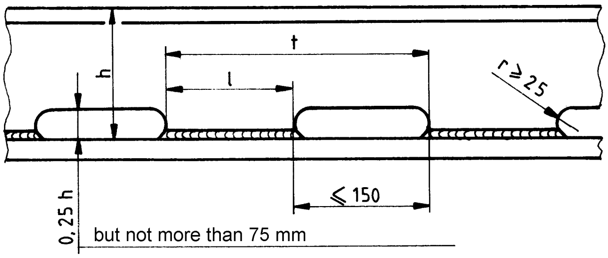
2.5 mm for $s = 4$ mm,
3.0 mm for $4 < s \le 10$ mm,
3.5 mm for $10 < s \le 15$ mm,
$0.25\,s$ for $s > 15$ mm.



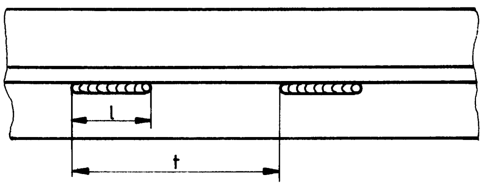
a) Staggered weld



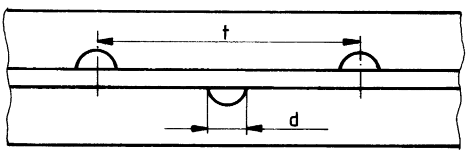
b) Chain weld



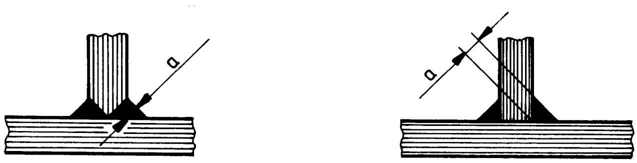
c) Scallop weld



d) Single intermittent weld



e) Staggered spot weld



f) Thickness a of fillet weld

Fig. 4.2.3.1 Types of fillet welds

Table 4.2.3.1-1

Item	Joint	α [1)]
1.	**Bottom Structure**	
1.1	Central girder to outer and inner bottom plating, inner bottom to outer plating	0.40
1.2	Watertight floors and parts of bottom girders forming boundaries of tanks	0.35
1.3	Floors and side bottom stringers to each other, as well as to inner and outer bottom plating – within 0.25 L_0 from the fore perpendicular and in the machinery space area	0.25
1.4	Above specified joints in the remaining areas	0.20
2.	**Side Framing**	
2.1	Frames (including web frames) and side stringers to shell plating within 0.25 L_0 from the fore perpendicular, in tanks, in machinery space, in way of ice strengthening as well as in the area of side reinforcements in ships intended for mooring at sea	0.17
2.2	Above specified joints in the remaining areas, beyond afterpeak	0.13
2.3	Above specified joints in the after peak	0.25
2.4	Side stringers to web frames	0.25
3.	**Deck and Deck Framing**	
3.1	Transverse and longitudinal deck girders to the plating	0.17
3.2	Webs of deck transverses to deck stringers and bulkheads	0.25
3.3	Deck beams and stiffeners	0.15
3.4	Deck cantilevers to the plating	0.35
3.5	Stringer plate of strength deck to sheer strake	0.45[2)]
3.6	Stringer plate of other decks and platforms to the shell plating	0.35[3)]
3.7	Hatch coamings to deck at hatch corners	0.45[2)]
3.8	Face bars of hatch coamings to coamings	0.25
3.9	Outer walls and bulkheads of superstructures and deckhouses to upper deck	0.35[3)]
3.10	Pillars to decks and inner bottom, pillar brackets to pillars, decks, inner bottom and other structural members	0.35
4.	**Bulkheads and Partitions**	
4.1	Bulkheads forming boundaries of the cargo or ballast tanks – at the circumference	0.35[3)]
4.2	Bulkhead stiffeners to the plating, beyond the peaks	0.15
4.3	Above specified joints in the peaks	0.25
4.4	Vertical and horizontal girders to the plating, beyond the peaks	0.17
4.5	Above specified joints in the peaks	0.30[3)]
4.6	Transverse bulkheads to longitudinal bulkheads	0.35[3)]
5.	**Foundations of Main Machinery and Boilers**	
5.1	Web plates of foundations to shell plating, tank top and deck	0.35[2)]
5.2	Web plates of foundations to their face plates	0.45[2)]
5.3	Foundation brackets to foundation web plates, outer plating, inner bottom and deck	0.35[2)]
5.4	Brackets to their face plates	0.25
6.	**Other Joints**	
6.1	Brackets interconnecting framing components	0.35
6.2	Ends of girders within 0.15 of their span from the supporting points	0.25

1) All welded joints of watertight structures are to be made with double continuous weld.
2) Full penetration welds are to be used.
3) Double continuous weld is required.

Table 4.2.3.1-2

Item	Type of fillet weld	β
1	Double continuous weld	1.0
2	Staggered, chain and scallop weld	t/l
3	Single continuous weld	2.0
4	Single intermittent weld	$2t/l$

t – weld pitch,
l – weld length (see Fig. 4.2.3.1).

4.2.3.2 In heavy loaded joints, the plate edges are to be bevelled to ensure full penetration or deep fusion weld. The following joints are to be welded with full penetration:
- strength deck stringer to sheer strake,
- in way of machinery and armament foundations (see Table 4.2.3.1-1),
- hatch coamings with deck at hatch corners,
- rudder horns and propeller shaft brackets to shell plating,
- rudder blade plating to the flange connecting the rudder blade with rudder stock.

4.2.3.3 For such joints as:
- transverse bulkhead to double bottom,
- structural elements in double bottom under bulkhead,
- joints of discontinuous girders (in order to ensure their continuity) with webs of the structure where the girders are interrupted,

the fillet weld thickness is to be increased or full penetration weld should be applied.

4.2.3.4 The weld thickness and cross-section of heavy loaded welded joints are subject to special consideration by PRS.

4.2.3.5 Structural elements and parts of members cut at the plating or at the crossing structures are to be coplanar. The maximum shift of the planes of interrupted structural elements and members is not to be greater than half of their thickness and not greater than that determined in Fig. 4.2.3.5.

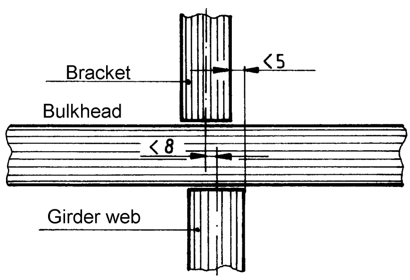


Fig. 4.2.3.5 Shift of interrupted planes

4.2.3.6 Double continuous welds are required:
- for watertight, oiltight and weathertight joints;
- within 0.25 L_0 from the fore perpendicular – for welding structural members to the bottom plating;
- within ice belt of ships with ice strengthening **L1A**, **L1** and **L2** (see Part C, 11.1.2.2);
- for welding side framing to the outer plating;
- in the area of pillars and at the ends of structural elements;
- in machinery and armament foundation and supporting structures;
- for all joints in the after peak;
- for joints inside the rudder blade, except the cases where slot welding is necessary;
- for connecting bottom central girder to the keel plate.

4.2.3.7 Intermittent welds may be used for less loaded joints – inside dry spaces and oil fuel tanks.

4.2.3.8 Inside ballast, cargo or fresh water tanks, inside the spaces where water may be accumulated or condensed, as well as inside empty spaces exposed to corrosion (such as rudder blades), continuous welds are to be applied for heavy or dynamically loaded joints, or scalloped welds – for less loaded joints.

4.2.3.9 The length of intermittent weld l (see Fig. 4.2.3.1) is not to be less than 15a and should amount to at least 50 mm. The distance between the weld sections (for chain and scallop welds amounting to $t - l$ and for staggered welds – $t/2 - l$) is not to be greater than 25 s or 150 mm – whichever is the lesser (s – the thickness of the thinner element, mm). The depth of scallops is not to be greater than 0.25 of the section depth and should not exceed 75 mm. The rounding radius of scallop is not to be less than 25 mm.

4.2.3.10 Double continuous welds are to be used in the area of pillars, at ends of structural members and at the places where supporting members (deck girders, floors, etc.) pass through structural members. The length of double continuous weld sections is not to be less than:
- bracket length – where applied;
- double depth of element – where brackets are not applied.

4.2.3.11 The distance from scallops of frames, deck beams, stiffeners, etc. to the ends of these elements and supports (supporting girders) is not to be less than double depth of the section, and the distance to the bracket ends is to be at least equal to half of the section depth.

4.2.3.12 Staggered spot welds, as well as single intermittent welds may be applied for joints in the second and higher tier of superstructures and deckhouses, as well as for elements in enclosed deck areas in the first tier of superstructures.

Where the thickness of section or plate is less than 7 mm, the spot weld may be used for joints in structures of casings and walls in these areas of hull, where neither variable or impact loads nor strong corrosive agents occur.

4.3 End Connections of Structural Members

4.3.1 End connections of structural members are to be, in general, butt joints.

Lap joints may be applied upon agreement with PRS, except:

- areas of increased vibrations,
- joints of web frames and girders,
- areas subjected to great concentrated loads.

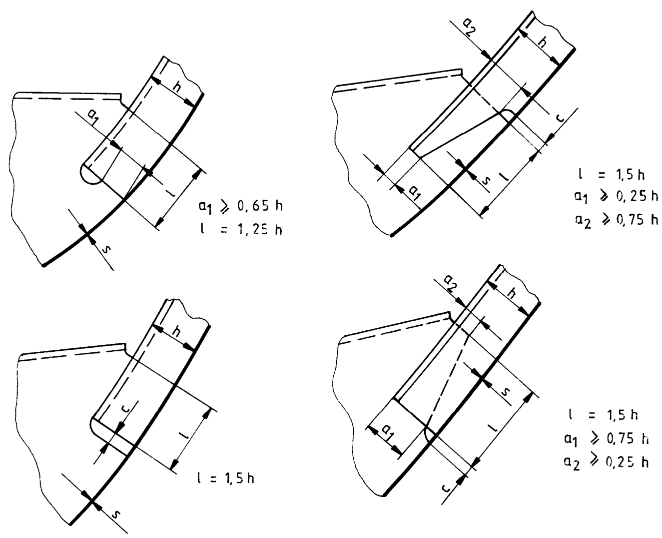
Brackets are to be, in general, made of material of the same yield stress as the adjacent elements of framing.

4.3.2 For bracket scantlings – see 13.8.

4.3.3 Free ends of bracket face plates or flanges are to be snipped to the width not greater than 3 times the thickness of the bracket web or 40 mm (whichever is the lesser). The length of the snipped part is to be equal to the width of flange or face plate.

4.3.4 In places of transition from the face plates of brackets to those of structural members, the butts of the face plates are to be kept at least 150 mm away from the toes of the brackets, and the angle formed by the bracket face plate and the direction of the members face plate is not to exceed 45°.

4.3.5 Joints of the lower ends of frames with bilge brackets or floors are to be made according to Fig. 4.3.5.



$c \leq 50$ mm or $c \leq 5\ s$, whichever is lesser.

Fig. 4.3.5 Connections of bottom ends of frames

4.3.6 Depending upon the design of the detail, the ends of face plates and/or webs of the structural members are to be snipped at ends over a length equal to 1.5 times the face plate width or 1.5 times the web depth. The blunting at the snipped free end is to be as follows:

– for face plate – equal to 3 times its thickness,
– for web – 10 ÷ 15 mm.

The distance between snipped end of structural element and the nearest member perpendicular to this element is to be, in general, not greater than 25 mm.

4.3.7 Stiffeners may be connected to the web plate of girders in one of the ways shown in Fig 4.3.7.

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

Connection lugs are to have a thickness not less than 75% of the web plate thickness.

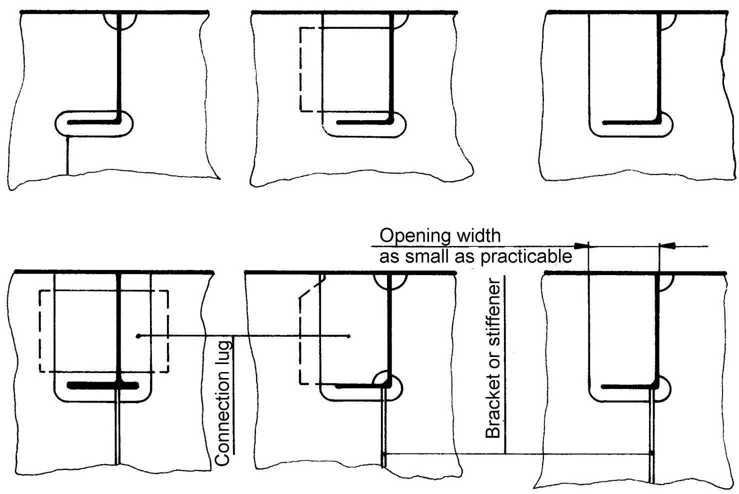


Fig. 4.3.7 Connection of a stiffener to the web plate of a girder

4.3.8 Connection of Different Material Structures

Bolted connections or special connecting elements (e.g. made with the use of explosive method) may be applied for connections of different materials.

These connections will be specially considered by PRS. The strength of connection is not to be less than that of the bolted connection and the corrosion protection is to be equally satisfactory.

5 PRINCIPLES OF MEMBERS SCANTLING

5.1 General

5.1.1 Graduation of Requirements

The requirements of the Chapter 5 apply to the hull structure strength analysis within the following extent:

– local strength within one structural member (e.g. part of the plate within its supporting stiffeners, stiffener simple girder), see Chapter 13;
– zone strength within one structure (relating to fragments of bottom, side, decks, bulkheads girders system, or hull modulus comprising such structural elements), see Chapter 14;
– general strength within the whole hull, see Chapter 15.

Requirements concerning fatigue strength analysis of a hull structure are given in Chapter 16.

5.1.2 Local Strength

The requirements regarding the local strength apply to the scantlings of plating, stiffeners, pillars, cross ties, brackets and ordinary girders. Boundary conditions for these members are known with sufficient accuracy. As a result, influence of the remaining part of the structure may be directly taken into account in formulae determining the scantlings of members in question.

5.1.3 Zone Strength

5.1.3.1 When the boundary conditions of girders, stiffeners or cross ties cannot be determined with sufficient accuracy and, as a result, the scantlings of girders cannot be defined on the basis of local strength requirements, the scantlings of girders are to be based on the zone strength analysis of the hull.

5.1.3.2 A zone may cover both part of the single structure (e.g. bottom, sides) and part of several structures in way of one or several cargo holds, tanks or other spaces. Zone boundaries are affixed in places of known boundary conditions.

5.1.3.3 Modelling the selected zone of the hull structure consists in reducing it to the system of principal girders supporting the local structural members.

5.1.3.4 Zone strength verification of the structure is required for specified cases specified in the present Part of the *Rules*.

5.1.4 General Strength

The requirements for the ship's general strength refer to the longitudinal bending and shear strength. In ships with combined hatch breadth in one cross-section (measured in the middle of the hatch length) greater than 0.6*b* (*b* – breadth of the strength deck in the cross-section), the additional stresses from the hull torsion are to be checked.

5.2 Basis for Requirements

5.2.1 Basic Problems

The following basic problems of the structure design:

– establishing the design loads,
– evaluation of the structure response to the loads,
– establishing the allowable ranges of the structural response parameters in respect of the assumed strength criteria,

have been solved for the relevant hull structure strength levels. The solutions are the basis for detailed requirements set forth in the present Part of the *Rules*.

5.2.2 Structure Loads

5.2.2.1 Static and dynamic loads imposed by the sea and by the cargo, stores, larger concentrated mass of cargo (e.g. carried vehicles) and equipment have been taken into account for the determination of design loads of hull structure given in present Part of the *Rules*. In specified cases, the impact loads imposed on the hull by waves have also been taken into account.

5.2.2.2 Design static loads are determined for given arrangement of the ship equipment, as well as for typical stores and cargo (e.g. carried vehicles) specified by the designer.

5.2.2.3 Requirements referring to design dynamic loads have been determined on the basis of long term prediction of ship motions within her operating life. The operating life is normally taken to correspond to 10^8 wave encounters in the North Atlantic. For ships of limited operational area lesser than described above values of dynamic loads are foreseen. The way of their determination is given in Chapters 15 and 17. Wave-induced loads determined according to recognized theories, model tests or full scale measurements may be accepted as equivalent for classification purposes.

5.2.3 Structure Response

5.2.3.1 Requirements concerning structure response such as stresses or strains in various points and sections of local members (plate panels, stiffeners or simple girders) have been based on the theories of elasticity and plasticity taking the assumed boundary conditions into account.

5.2.3.2 The thickness of plating exposed to lateral pressure is to be determined from the following formula:

$$t = 18\,k_a s\sqrt{\frac{p}{\sigma}} + t_k\,,\quad \text{[mm]} \qquad (5.2.3.2\text{-}1)$$

k_a – correction factor depending on aspect ratio of plate field,

$$k_a = \left(1 - 0.27\frac{s}{l}\right)^2 \qquad (5.2.3.2\text{-}2)$$

k_a need not be greater than 0.88;
s – length of shorter side of plate field, [m];
l – length of longer side of plate field, [m];
p – design lateral pressure imposed on plate field, [kPa];
t_k – corrosion addition (see 2.5), [mm];
σ – permissible stresses, [MPa].

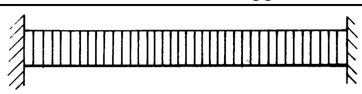
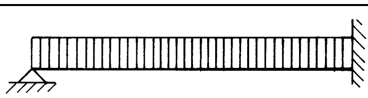
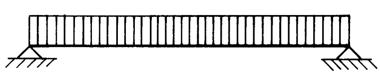
5.2.3.3 For stiffeners exposed to lateral pressure acting on the supported plating, the required section modulus W is given as a function of boundary conditions at the stiffeners ends and the permissible bending stress:

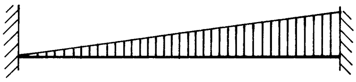
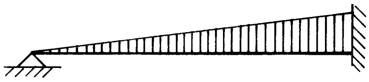
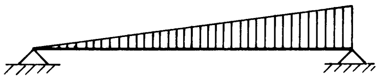
$$W = \frac{1000\,q\,l^2}{m\,\sigma}, \quad [\text{cm}^3] \qquad (5.2.3.3)$$

q = $p\,b$;
p – see 5.2.3.2;
b – width of plating strake supported by stiffener in question, [m];
l – stiffener span, [m];
σ – permissible bending stress, [MPa];
m – bending moment coefficient taking into account boundary and load conditions of the stiffener. The values of m coefficient are given separately for particular groups of structural members in Chapter 13. For scantling the structural members within the scope of elastic deflection, the values of m coefficient have been determined directly from general elastic bending theory.

In Table 5.2.3.3, the values of coefficient m for specified load and boundary conditions, have been given.

Table 5.2.3.3
Values of *m* and k_t coefficients

Load and boundary conditions	Bending moment and shear force factors		
Position	1	2	3
1 Support / 2 Field between supports / 3 Support	m_1 k_{t1}	m_2 –	m_3 k_{t3}
	12.0 0.50	24.0 –	12.0 0.50
	– 0.38	14.2 –	8.0 0.63
	– 0.50	8.0 –	– 0.50

Position	1	2	3
	15 0.30	23.3 –	10 0.70
	– 0.20	16.8 –	7.5 0.80
	– 0.33	7.8 –	– 0.67

5.2.3.4 The sectional area requirement for stiffeners, subject to shear stress, is given as a function of boundary conditions and allowable shear stress.

The value of cross-sectional area of a stiffener is determined from the following formula:

$$A = 10\frac{k_t P}{\tau}, \quad [\text{cm}^2] \qquad (5.2.3.4)$$

τ – permissible shear stress, [MPa];
P – total transverse load on the stiffener, [kN];
k_t – transverse force coefficient taking into account boundary and load conditions.

The values of k_t coefficient for some load and boundary conditions are specified in Table 5.2.3.3.

5.2.3.5 The scantlings of elements of girders subjected to bending moments are determined in accordance with the provisions set forth in 5.2.3.3 for stiffeners. The given formulae are applicable to simple girders, i.e. girders which may be modelled by a single-span beam with known boundary conditions.

5.2.3.6 Where girders do not meet the conditions specified in 5.2.3.5, the structural response is to be determined on the basis of adequate methods of the zone strength analysis.

It is recommended to use computerized matrix methods of structural analysis based on the bar idealization of structure or by means of other types of finite elements.

5.2.3.7 Requirement concerning response of hull structure to the hull girder bending loads is based on the linear bending theory of simple beam.

5.2.3.8 Special means are to be provided in way of the afterbody and machinery space to preclude excessive vibration of the structure. The guidelines referring to the above problem are given in PRS *Publication No. 2/I – Prevention of Vibration in Ships*.

6 BOTTOM STRUCTURES

6.1 General

6.1.1 Application

The requirements of the present Chapter apply to the double and single bottom structures.

Sub-chapters 6.2 and 6.3 relate to the double bottom, and sub-chapters 6.6 and 6.7 to both types of the bottom.

6.1.2 Extension of Double Bottom

6.1.2.1 It is recommended that the double bottom is provided where its available height is not less than 600 mm.

6.1.2.2 Where possible, the double bottom should be provided within the area from the fore peak bulkhead to the after peak bulkhead.

6.1.2.3 The bilge is to be overlapped by the inner bottom as far as possible, particularly in the fore end of the ship.

6.1.2.4 In ships which are to be affixed with subdivision mark in the symbol of class, the overlapping of the bilge is deemed adequate if the line of intersection of the margin plate with the bilge plating does not lie below the horizontal plane passing through the point A amidships, as shown in Fig. 6.1.2.4.

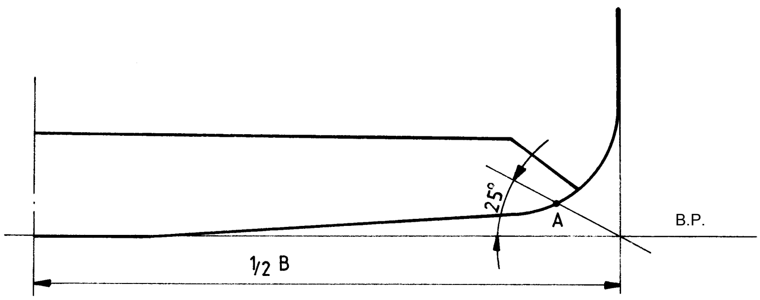


Fig. 6.1.2.4 Overlapping the bilge by the margin plate

6.2 Double Bottom Structure

6.2.1 General Requirements

Where the seating frame of the main engines, thrust bearings and boilers is fastened directly to the inner bottom, the floors, longitudinals and inner bottom plating are to comply with the relevant requirements of Chapter 12.

In way of the main engine, thrust bearing and boilers, the bottom structure is to be adequately strengthened.

Strengthening is also to be applied under pillars and bulkheads or walls supporting the upper parts of hull structure.

As far as possible the pillars placed directly on the double bottom is to be avoided, and adequate supporting of the above structure, where necessary, should be assured by application of the supporting bulkheads and divisions.

6.2.2 Framing System

6.2.2.1 As a rule in ships with length L_0 > 100 m, double bottom should be longitudinally stiffened. In smaller ships transverse stiffening system is allowed.

6.2.2.2 If the bottom is longitudinally stiffened, the longitudinals are to pass continuously through the floors within $-0.25\ L_0 \le x < +0.25\ L_0$ amidship.

In ships with 40 m < L_0 ≤ 100 m, the longitudinals may be cut at transverse members within $-0.25\ L_0 \le x < +0.25\ L_0$ amidships provided that brackets passing through slotted cuts in the floors or bulkheads, and connecting the ends of the longitudinals are fitted, or the continuity is to be provided otherwise;

Beyond the region $-0.25\ L_0 \le x \le 0.25\ L_0$ in ships with $L_0 \ge 40$ m and over the whole length of ships with $L_0 < 40$ m, the longitudinals may be cut at bottom floors and welded to them;

6.2.3 Arrangement of Bottom Girders

The arrangement of bottom girders and plate floors is to comply with the requirements given in 6.2.4 ÷ 6.2.6.

The arrangement of girders in the double bottom may be different, provided that the requirements for local strength (Chapter 13) and possibly for zone strength (Chapter 14) are complied with.

6.2.4 Bottom Centre Girder and Duct Keel

6.2.4.1 Bottom centre girder is to be fitted in the ship's centre line. It is to extend fore and aft as far as possible. The centre girder is to be continuous within $-0.3\ L_0 \le x \le 0.3\ L_0$.

6.2.4.2 Instead of the bottom centre girder a duct keel made of two longitudinal girders fitted on both sides of the centre line may be applied. The distance between girders is not to exceed the value determined from the formula:

$$b = 0.004\,L_0 + 1.0\,, \quad [\text{m}]\,. \qquad (6.2.4.2)$$

This distance may be increased after special consideration by PRS. Supporting plates or transverse stiffeners with brackets are to be fitted (with a spacing not exceeding 0.8 m) on the outer and inner bottom plating between these girders in line with each frame.

6.2.4.3 Where the duct keel is extended over a part of the ship's length only, and the ordinary centre girder is applied in the remaining part, they have to overlap at the length equal to at least a half of the double bottom height and flanged brackets are to be fitted at the ends of girders. If the alteration of the centre girder structure is situated within $-0.3\ L_0 \leq x \leq 0.3\ L_0$, the length of brackets is to be equal to at least the double bottom height and in other cases – to at least 2/3 of the double bottom height.

6.2.5 Arrangement of Side Girders

6.2.5.1 Side girders in the double bottom are to be fitted so that the distance between the side girder and margin plate, or centre girder, or duct girder, as well as the distance between adjacent side girders does not exceed the following values:

5 m – for longitudinal framing,
4 m – for transverse framing.

6.2.5.2 Side girders should be extended forewards and aftwards as far as possible. They should terminate at the floors or bulkheads. On the opposite side of these floors or bulkheads, brackets, constituting extension of the girders over the length not less than one frame spacing, should be applied.

6.2.5.3 Girders in the machinery space are to be fitted in accordance with the location of the engine seatings and other gear of substantial weight.

6.2.6 Arrangement of Plate Floors in Double Bottom

6.2.6.1 In the double bottom with transverse framing beyond the region of deep tanks and machinery, the plate floor spacing is not to be greater than:

- six frame spacings for $T \leq 2$ m;
- five frame spacings for $2 \leq T \leq 5$ m;
- four frame spacings for $T > 5$m.

6.2.6.2 In the double bottom with longitudinal framing, the plate floor spacing is not to be greater than 3.0 m, and in way of deep tanks it is not to exceed 2.5 m.

6.2.6.3 In the double bottom within the machinery space with transverse framing, plate floors are to be fitted at every frame.

6.2.6.4 In the double bottom within the machinery space with longitudinal framing, plate floors are to be fitted with spacing not more than the double bottom height. In way of the engine seating between external girders adjacent to the seating girders, plate floors are to be fitted with spacing two times lower than above.

6.2.7 Arrangement of Supporting Plates in Double Bottom

6.2.7.1 Supporting plates are to be fitted at both sides of the bottom centre girder and at least at one side of stringers, duct girders and margin plate. In the case of longitudinal framing, they are to extend to the nearest longitudinal. See also 6.3.3.4.

6.2.7.2 A face plate or flange is to be provided for the free edge of the supporting plate.

6.2.7.3 In longitudinally stiffened double bottom, the supporting plate spacing is not to exceed double bottom height and on the duct girders – half of double bottom height.

Where the ship side is transversely framed, supporting plates in double bottom on the margin plate are to be fitted at every frame.

Docking brackets, extended to the nearest longitudinal, are to be fitted between supporting plates on the centre girder.

6.2.7.4 In transversely stiffened double bottoms, supporting plates, constituting parts of bracket floors, are to be fitted on frames without plate floors at bottom centre girder and at margin plate.

6.2.8 Manholes, Holes and Cut-outs

6.2.8.1 To provide access to all parts of the double bottom, manholes are to be cut in the inner bottom plating and holes are to be cut in plate floors and longitudinal girders. The openings, their arrangement and size are to comply with the requirements of sub-chapter 3.5 and with those given below.

6.2.8.2 Manholes in the inner bottom plating are to comply with the requirements of *Part III – Hull Equipment*.

6.2.8.3 Manholes in the inner bottom plating provided for the access to the fuel tanks in way of the machinery space are to have coamings, the height of which is to be equal to at least 100 mm.

6.2.8.4 The diameter of the lightening holes in brackets of the bracket floors is not to be greater than 1/3 of the breadth of the brackets.

6.2.8.5 The distance between edges of two adjacent holes is not to be less than half the breadth of the greater hole.

6.2.8.6 Only indispensable number of cut-outs and manholes is to be provided in side girders and plate floors within $x > 0.25\ L_0$.

6.2.8.7 The drain holes and air holes are to be cut in compliance with 3.5.1.1 and 3.5.1.5.

6.2.8.7.1 Openings are not to be cut in:
- the keel plate;
- the bilge strake within $-0.3\ L_0 \leq x \leq +\ 0.3\ L_0$; the necessary holes are to be located as far from the bilge keel as possible.

6.2.8.7.2 Holes are normally not to be cut in:
- bottom centre girder within $x > 0.25\ L_0$,
- side girders and floors under the supports and at the ends of longitudinal partitions,

- bottom centre girder and in side girders between a transverse bulkhead and adjacent plate floors,
- floors in areas adjacent to the margin plate and centre girder, as well as in way of toes of transverse brackets supporting seatings of the main machinery.

In special cases, openings may be cut in members under consideration, provided they are reinforced by stiffeners or by a flat bar welded to the edge.

Location and dimensions of holes may be also assumed on the basis of stress analysis in accordance with the requirements given in Chapters 13 and 14.

6.2.9 Discontinuity of the Double Bottom

In areas where double bottom terminates, the smooth transitions from double bottom girders to single bottom girders are to be provided.

The gradual transition of inner bottom plating into face plates of bottom centre girder and bottom side girders, at the length equal to at least three frame spacings, is to be provided. The width of these face plates at the double bottom ends is not to be less than half the distance between adjacent side girders.

Margin plates are to be extended outside the double bottom and are to form a bracket, the length of which is not to be less than three frame spacings, with flat bar or flange at the free edge.

6.2.10 Alteration in the Double Bottom Depth

6.2.10.1 Change in the depth of the double bottom may be effected in the form of two leaps or a step. Leaps of inner bottom are to be arranged on a transverse bulkhead and plate floor.

Both leaps may be arranged on plate floors after special consideration by PRS in each particular case.

6.2.10.2 When the depth of the double bottom is changed abruptly, the change (step) is to be normally arranged on a transverse bulkhead.

6.2.10.3 In way of a step, the inner bottom plating of smaller height is to be extended by a distance of three frame spacings when $L_0 \geq 90$ m and by two spacings when $L_0 < 90$ m.

When the step is outside $-0.25\ L_0 \leq x \leq 0.25\ L_0$ or when its height is less than 660 mm, the double bottom structure in way of extension will be specially considered by PRS in each particular case.

6.2.10.4 Continuity of structure and reduction of stress concentration are to be provided in places where the height of bottom centre girder, side girders, margin plates and inner bottom longitudinals, if applied, is altered.

6.2.11 Drain Wells in Double Bottom

The depth of drain wells is normally not to be greater than that of the double bottom within this region decreased by 460 mm. In ships with subdivision mark affixed in the symbol of class, wells are not to be arranged below the horizontal line determined in 6.1.2.4. The well adjacent to the outer bottom plating may be arranged only in the shaft tunnel afterbody.

6.3 Scantlings of Double Bottom Structural Members

6.3.1 Double Bottom Depth

6.3.1.1 The double bottom depth is to be sufficient to assure free access to all bottom parts.

It is recommended that the depth is not less than 650 mm.

6.3.1.2 The height of centre girder and the attached plate floors in principle is not to be less than that determined from the formula:

$$h_d = 250 + 20B + 50T, \quad \text{[mm]} \qquad (6.3.1.2)$$

For ships with a great rise of floors, the value of h_d may have to be increased.

6.3.1.3 Where requirements of 6.3.1.1 and 6.3.1.2 concerning bottom depth are not complied with, the bottom strength is to be verified according to requirements of Chapter 14.

6.3.1.4 In the machinery space, in way of seating of internal combustion main engine and the gear, it is recommended that the height of the double bottom is increased by 45% where the sump tank is under the main engine, and by 30% in other cases.

6.3.2 Outer and Inner Bottom Plating

6.3.2.1 The thickness of plating of outer and inner bottom is to be determined according to 13.2.2 and 13.4.2.

6.3.2.2 The thickness of bottom plating in the forebody is to be additionally checked for slamming pressure according to 6.7.2.

6.3.2.3 The thickness of a keel plate is not to be less than that of the adjacent bottom plating.

6.3.2.4 The width of a keel plate is not to be less than that determined from the following formula:

$$b = 800 + 5L_0, \quad \text{[mm]}. \qquad (6.3.2.4)$$

6.3.2.5 The thickness of the bilge plating is not to be less than that of the adjacent bottom plating and the ship's side plating.

6.3.2.6 When, according to the requirements of 2.2, steel grade higher than A is required for bilge strake or outer bottom strake, to which an effective longitudinal bulkhead is attached, the breadth of the strake is not to be less than that required by 6.3.2.4.

6.3.2.7 The breadth of the sloped margin plate over the entire ship's length is not to be less than:

$$b = 0.0035L_0 + 0.40\,, \quad [\text{m}] \qquad (6.3.2.7)$$

6.3.2.8 The breadth of the horizontal margin plate is not to be less than the breadth of the tank side bracket increased by the height of the ship side frame section and additionally by 50 mm.

Where bottom members are attached to ship side frames without tank side brackets, the breadth of the horizontal margin plate is not to be less than that determined from formula 6.3.2.7.

6.3.2.9 The thickness of margin plate is to be greater than that of the inner bottom, required in 6.3.2.1, in the same ship's region, as follows:
– the thickness of horizontal margin plate is to be increased by 1 mm,
– the thickness of sloped margin plate is to be increased by 2 mm.

The thickness of margin plate in the machinery space is not to be less than that of inner bottom plating within the area in question.

6.3.2.10 The thickness of the sump walls and bottom is to be greater by at least 2 mm than that of the watertight floors within the area in question.

6.3.2.11 The thickness of floors, longitudinal girders and inner bottom plating forming boundaries of sea chest is to be increased by at least 2 mm in respect of the minimum thickness required for double bottom structure (including outer bottom plating), or the thickness required in 13.4.2, whichever is the greater. The strength of chest walls is not to be less than the local strength assumed for the outer plating arranged in a given portion of the ship.

6.3.3 Double Bottom Stiffeners

6.3.3.1 The scantlings of longitudinal and transverse frames in the outer and inner bottom are to be determined in compliance with 13.5.

6.3.3.2 The scantlings of outer bottom frames in the forebody are to be additionally checked for the action of slamming pressure in compliance with 6.7.

6.3.3.3 When determining the scantlings of double bottom frames, it should be taken into account that vertical struts fitted between longitudinal or transverse frames of inner and outer bottom are normally not regarded as the effective support of the frames in question. Where the vertical struts are applied, the section modulus for bottom frames may be reduced after special consideration by PRS. Where the stiffeners of outer and inner bottom have the same section modulus, then a strut fitted in midst of their span may be considered for reduction of section moduli of stiffeners by not more than 35%. See also 13.7.4.

6.3.3.4 The supporting plates or transverse stiffeners and end brackets are to be fitted on inner and outer bottom plating between duct girders at every frame. The height of brackets is not to be less than that of the stiffener. The scantlings of supporting plates or stiffeners are to be determined from zone strength analysis of the double bottom (see Chapter 14).

6.3.4 Double Bottom Girders

6.3.4.1 The scantlings of bottom longitudinal girders and plate floors of double bottom are to be determined in compliance with 13.6. Their thickness in the fore peak is not to be less than:

$$t = 12\,s + t_k\,, \quad \text{[mm]} \qquad (6.3.4.1)$$

s – spacing of stiffeners, [m];
t_k – corrosion addition – see 2.5.

The scantlings of girder webs (in single or double bottom) in the fore part of the ship are to meet additionally the requirements of 6.7.4.

6.3.4.2 Plates and stiffeners of double bottom girders forming bottom tank boundaries are also to be in compliance with the requirements applicable to the scantlings of plating and stiffeners of tank bulkheads.

6.3.5 Stiffeners of the Girders

6.3.5.1 Stiffeners are to be fitted at every floor within $x > 0.25\ L_0$ and at every floor of the height exceeding 900 mm outside this area.

For longitudinal framing, the stiffeners are to be applied in line with each longitudinal, whereas for transverse framing, the stiffener spacing is not to be greater than 1.5 m (see also 13.5.3.6).

6.3.5.2 In the double bottom with transverse framing, longitudinal girders are to be stiffened at every frame (see also 6.2.7).

The longitudinal girders are to comply with the requirements for buckling strength given in Chapter 13.

6.3.6 Supporting Plates

6.3.6.1 The thickness of supporting plates fitted at the bottom centre girder, duct girders, side girders and at the margin plate being part of open floors, is not to be less than that determined in compliance with 13.2.2.

6.3.6.2 The thickness of supporting plates not being part of open floors, provided in compliance with the requirements of 6.2.7, is to be not less than that of plate floors within the area in question.

6.3.6.3 The breadth of supporting plates of open floors measured on the inner bottom level is not to be less than 0.75 of the bottom height in way of centre girder, duct girder and margin plate and not less than 0.35 of the bottom height in way of side girders. Where frames of an open floor are not continuous in way of side girder, the supporting plates are to be fitted on both sides of the girder.

6.3.6.4 The free edge in a supporting plate is to be stiffened by a face plate or a flange of the width equal to 10 times the plate thickness is to be applied; the flange width need not exceed 90 mm.

6.4 Single Bottom Structural Arrangement

6.4.1 General

6.4.1.1 Application of pillars set on the bottom should, as far as possible, be avoided, and appropriate support of above structure is to be assured, if necessary, by means of supporting bulkheads and divisions.

6.4.2 Framing system

6.4.2.1 It is recommended that single bottom in ships with length $L_o > 65$ m is longitudinally stiffened.

6.4.2.2 If the bottom is longitudinally stiffened, the bottom longitudinals are to comply with following requirements regarding continuity:

- in ships with $L_o \geq 40$ m, the longitudinals are to pass continuously through the floors, transverse bulkheads and divisions within $-0.25\ L_0 \leq x < 0.25\ L_0$ amidship;
- in ships with $L_0 < 40$ m over all length of the ship, and in ships with $L_o \geq 40$ m outside $-0.25\ L_0 \leq x < 0.25\ L_0$ amidship, the longitudinals can be cut and welded to them.

6.4.3 Arrangement of Bottom Girders

6.4.3.1 Bottom centre girder is to be fitted in the ship's centre line. It is to extend fore and aft as far as possible. The centre girder is to be continuous within $-0.3\ L_0 \leq x \leq 0.3\ L_0$.

6.4.3.2 Side girders are to be fitted at the distance not exceeding 2.5 m. It is recommended that they are continuous when passing through the transverse bulkheads within $-0.3\ L_0 \leq x \leq 0.3\ L_0$.

6.4.3.3 Girders in the machinery space are to be fitted in compliance with the location of the engine seatings and other main gear.

6.4.4 Arrangement of Floors

6.4.4.1 Within machinery space area the floors are to be fitted at each frame.

6.4.4.2 In the transversally stiffened bottom the plate floors are to be fitted at each frame, over the whole length of the ship.

6.4.4.3 In the longitudinally stiffened bottom arrangement of the plate floors outside machinery space and the ship ends shall be determined on the basis of local and zone strength requirements.

6.5 Scantling of Single Bottom Girders

6.5.1 Height of Single Bottom

6.5.1.1 The height of centre girder and the attached plate floors in principle is not to be less than that determined from the formula:

$$h = 0.055\,B_1\,,\ [\mathrm{m}] \qquad (6.5.1.1)$$

B_1 – breadth of space under consideration, measured in the middle of its length as follows:

a) in case of single sides – as a distance between sides or distance between side and longitudinal bulkhead, at the level of the upper edge of the floor,
b) in case of double sides – as a distance between inner sides or distance between inner side and longitudinal bulkhead.

6.5.1.2 The height of floors in the centre plane can be decreased by 10% provided that the floor section modulus will not be less than required in 6.5.3.4. In a distance of 3/8 of the ship's breadth from the centre plane height of the floors is to be at least 50% of that required in the centre plane. In particular cases PRS may accept deviation from this requirement.

6.5.1.3 In the single propelled ships upper edges of the floors in the afterpeak are to terminate over stern tube.

6.5.2 Bottom Plating

6.5.2.1 Requirements 6.3.2.1 to 6.3.2.6 given for double bottom are to be complied with.

6.5.3 Girders and Bottom Frames

6.5.3.1 Bottom longitudinals scantlings are to be determined in compliance with 13.5.

6.5.3.2 The scantlings of the bottom frames in the forebody are to be additionally checked for the action of slamming pressure in compliance with 6.7.

6.5.3.3 For longitudinal stiffening system of the bottom, scantlings of floors and girders is to be established on the basis of stresses analysis as required in Chapter 14.

Provisions of 6.5.3.4 to 6.5.3.6 are to be complied with.

6.5.3.4 Section modulus of the plate floors is not to be less than that determined from the formula:

$$W = KaT_1B_1^{\ 2},\ [\text{cm}^3] \qquad (6.5.3.4)$$

K = 7.8 – 0.2 B_1;
a – floors spacing, [m];
T_1 – design ship's draught or 0.65 H, whichever is greater, [m];
B_1 – see 6.5.1.1.

The thickness of the floors is to be equal to at least 0.01 of their height in the centre plane plus 3.5 mm, but doesn't need to be greater than thickness of the bottom plating.

6.5.3.5 In the single bottom amidship, the bottom centre girder plate thickness is not to be less than determined from the formula:

$$t = 0.06L_o + 6,\ [\text{mm}] \qquad (6.5.3.5)$$

The thickness of the centre girder at the distance of 0.1 L_0 from perpendiculars can be 1 mm less then that required amidship.

6.5.3.6 In the single bottom, the bottom side girder plate thickness amidship is not to be less than determined from the formula:

$$t = 0.06L_o + 5,\ [\text{mm}] \qquad (6.5.3.5)$$

The thickness of the side girder at the distance of 0.1 L_0 from perpendiculars can be by 1 mm less than that required amidship, but is not to be less than 5 mm.

6.5.4 Stiffeners of Single Bottom Floors and Girders

6.5.4.1 Scantlings of the single bottom girders face plates are to comply with the given below requirements:

– the width is not to be less than 1/20 of distance between tripping brackets or 75 mm, depending on that whichever is greater,
– the thickness is not to be less than 1/30 of symmetrical face plate width, and 1/15 of non-symmetrical face plate width, and in each case not less than girder plate thickness.

6.5.4.2 Section area of the floors' face plates with the minimum height determined from the formula 6.5.1.1 is not to be less than that determined below:

– in machinery space area $A = 5.0\ t,\ [\text{cm}^2]$ (6.5.4.2-1)
– outside machinery space $A = 3.5\ t,\ [\text{cm}^2]$ (6.5.4.2-2)

6.5.4.3 The floors' face plates can be substituted by flanges provided that section modulus of the floor is increased by 5%. The flange width is to comply with requirements of 6.5.4.1. The flanged floors are not to be applied in machinery space, after-peak, and in ships with L_o > 30 m also in area 0.25 L_o abaft forward perpendicular.

6.5.4.4 The scantlings of the floors' and longitudinals' webs stiffeners, as well as their arrangement shall comply with the requirements of 3.6.

6.5.5 Bar Keel

The scantlings of a bar keel are not to be less than:

depth: $h = 100 + 5L_0$, [mm] (6.5.5-1)

thickness: $t = 10 + 0.6L_0$, [mm] (6.5.5-2)

6.6 Common Requirements for the Ships with Single and Double Bottom

6.6.1 Arrangement of Girders in Peaks

Plate floors or longitudinal girders in fore and after peaks supporting longitudinal or transverse frames are to have spacing not exceeding 1.8 m. Heavy intersecting girders or bulkheads arranged at distances generally not exceeding the smaller of 0.125 *B* or 5 m are to support the above-mentioned girders.

6.6.2 Complex Girder Systems in Bottom

Where the bottom girders are connected with girders of other structures (e.g. side or bulkhead girders) thus forming a complex girder system, it may be required to check their scantlings on the basis of stress analysis according to Chapter 14.

6.6.3 Bilge Keels

A bilge keel is to be attached to the plating by the intermediate member (flat bar) over the full length of the bilge keel.

Weld connection of the bilge keel to the intermediate member is to be weaker than that of the member to the shell plating.

Bilge keel ends are to be smoothly tapered or rounded and are to be in line with inner stiffenings of the hull.

6.7 Bottom Strengthening in the Forebody

6.7.1 General

The bottom forward is to be strengthened against slamming according to the requirements given below.

6.7.2 Thickness of Bottom Plating

6.7.2.1 In ships of length $L_0 \geq 100$ m, the thickness of bottom plating below the waterline at $d = 0.05\ T_{bd}$ above the keel, is to be not less than:

$$t = 0.9 k_u k_r s \sqrt{\frac{p_u}{k}} + t_k, \quad \text{[mm]} \qquad (6.7.2.1\text{-}1)$$

$k_u = \left(1.1 - 0.25\frac{s}{l}\right)^2$; $1.0 \geq k_u \geq 0.72$ is to be taken;

$k_r = \left(1 - 0.5\frac{s}{r}\right)$ – correction factor for curved plates;

r – plate curvature radius, [m];
p_u – slamming pressure, determined in accordance with 6.7.5 [kPa];
T_{bd} – as in 6.7.5;
s – spacing between stiffening measured along the plating, [m];
l – span of stiffener or girder, [m];
t_k – corrosion addition – see 2.5 [mm].

For ships of length $L_0 < 100$ m, the bottom plating thickness is not to be less than:

$$t = 0.9\, s\sqrt{p_u} + t_k, \quad \text{[mm]} \qquad (6.7.2.1\text{-}2)$$

6.7.2.2 Above the waterline defined in 6.7.2.1, the plating thickness is to be gradually changed from the above determined value to the thickness of the side plating in the hull cross-section under consideration.

6.7.3 Scantlings of Stiffeners

6.7.3.1 The section modulus of bottom longitudinals or floors supporting the bottom plating defined in 6.7.2.1 and 6.7.2.2, after deduction of corrosion allowances, is not to be taken less than:

$$W = \frac{0.2\, l^2 s\, p_u}{k}, \quad \text{[cm}^3\text{]} \qquad (6.7.3.1)$$

p_u – slamming pressure, determined in accordance with 6.4.5.

For the remaining symbols, see 6.7.2.1.

6.7.3.2 The cross-sectional area of the frame web is not to be less than:

$$A_s = \frac{0.03}{k}\left(1 - s\right) s\, p_u + 10\, h\, t_k, \quad \text{[cm}^2\text{]} \qquad (6.7.3.2)$$

p_u – slamming pressure, determined in accordance with 6.7.5;
h – stiffener height, [m].

For the remaining symbols, see 6.7.2.1.

6.7.4 Girder Webs

6.7.4.1 The net weld connection area of continuous stiffeners with girders is to satisfy the following formula:

$$2A_s \leq 1.7A_{pm} + A_{ps} \qquad (6.7.4.1)$$

A_{pm} – connection area at flange, [cm^2];
A_{ps} – connection area at web, [cm^2];
A_s – see 6.7.3.2.

6.7.4.2 In the double bottom below the waterline at $d = 0.05\ T_{bd}$ above the keel, the spacing of stiffeners on web plates or bulkheads near the shell plating is not to exceed:

$$s_u = 0.09t\,, \quad [\text{m}] \qquad (6.7.4.2)$$

t – thickness of web or bulkhead plating, [mm].

6.7.4.3 The sum of cross-sectional shear areas at the ends of girder or girder system supporting any specified area of the bottom is not to be less than:

$$\sum A_i = \frac{c_3}{k} l_w b_w p_u\,, \quad [\text{cm}^2] \qquad (6.7.4.3\text{-}1)$$

p_u – slamming pressure, taken according to 6.7.5, in the middle of the girder system area considered, [kPa];

$l_w,\ b_w$ – length and breadth of the loaded area supported by the girder or girder system, [m];

$c_3 = 0.05\left(1 - \frac{10\,l_w b_w}{L_0 B}\right)$, but not less than 0.025. (6.7.4.3-2)

6.7.5 Slamming Pressure

The design slamming pressure imposed on bottom plating in way of the fore-body is to be determined from the following formulae:

– for ships of length $L_0 < 100$ m:

$$p_u = 300\sqrt{L_0}\left(1 - 20\frac{T_{bd}}{L_0}\right), \quad [\text{kPa}] \qquad (6.7.5\text{-}1)$$

– for ships of length $L_0 \geq 100$ m:

$$p_u = \frac{C_1 C_2}{T_{bd}} B_{bd}\left(0.56 - \frac{L_0}{1250} - \frac{u}{L_0}\right), \quad [\text{kPa}] \qquad (6.7.5\text{-}2)$$

$$C_1 = \sqrt[3]{L_0} \quad \text{for} \quad L_0 < 150 \text{ m}, \qquad (6.7.5\text{-}3)$$

$$C_1 = \sqrt[3]{225 - 0.5L_0} \quad \text{for} \quad L_0 \geq 150 \text{ m}, \qquad (6.4.5\text{-}4)$$

$$C_2 = 1675\left(1 - \frac{20T_{bd}}{L_0}\right); \qquad (6.7.5\text{-}5)$$

T_{bd} – design heavy weather ballast draught at FP, [m];

B_{bd} – the breadth of the bottom at the waterline positioned at $z = 0.15\ T_{bd}$ above the keel measured at the cross-section considered, [m]; B_{bd} is not to be taken greater than $1.35\ T_{bd}$ or $0.55\sqrt{L_0}$, whichever is the lesser;

u – distance from FP to the considered cross-section of the hull, [m]; the assumed value of u need not be less than u_1 calculated from the formula:

$$u_1 = \left(1.2 - \sqrt[3]{\delta} - \frac{L_0}{2500}\right) L_0\,, \quad [\text{m}] \qquad (6.7.5\text{-}6)$$

For ships of length $L_0 < 100$ m, the pressure p_u determined from formula 6.7.5-1 is to be applied to $x > 0.3\ L_0$. From the hull section $x = 0.3\ L_0$ aft, this pressure may be reduced linearly to zero at $x = 0.1\ L_0$.

For ships of length $L_0 \geq 100$ m, the assumed distribution of slamming pressure p_u acting on the bottom is shown in Fig. 6.7.5.

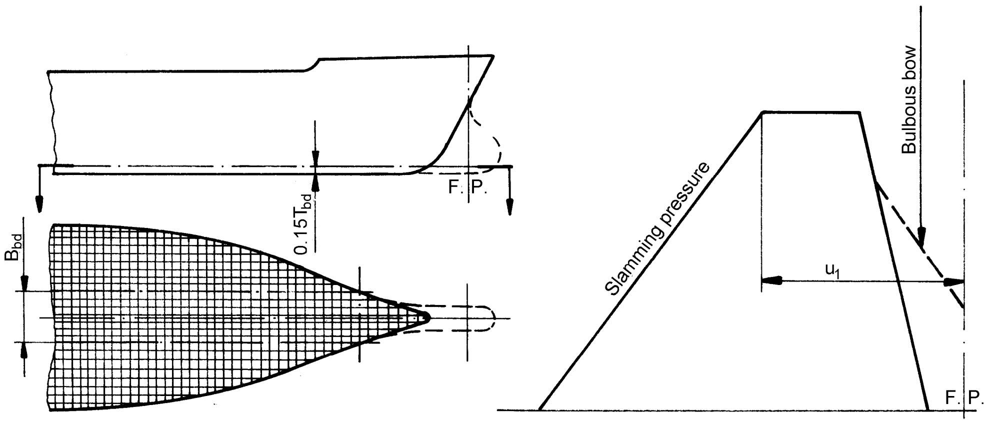


Fig. 6.7.5 Distribution of slamming pressure acting on the bottom

If the ship at the design ballast draught T_{bd} is intended to have full ballast tanks in the forebody and the load from the ballast will act on the shell plating, the slamming pressure may be reduced by 14 h, [kPa] (h – height of the ballast tank, [m]).

7 SIDE STRUCTURES

7.1 General

7.1.1 Application

The requirements of this Chapter apply to ship's side structure in compliance with the definition given in A/2.5.

7.1.2 Span of Main Frames

The lower span of the frame in way of longitudinally stiffened single bottom (see Fig. 7.1.2) is to be determined from the following formula:

$$l = l_1 - 0.3r - 1.5(w - h), \quad [\text{m}] \qquad (7.1.2)$$

l_1 – vertical distance between the bottom and the lowest deck or side stringer supporting frames, [m];
r – bilge radius, [m];
w – the largest depth of bilge bracket measured perpendicularly to the flange, [m];
h – height of frame, [m].

In other cases, the span of frames is to be taken according to 3.2.1.

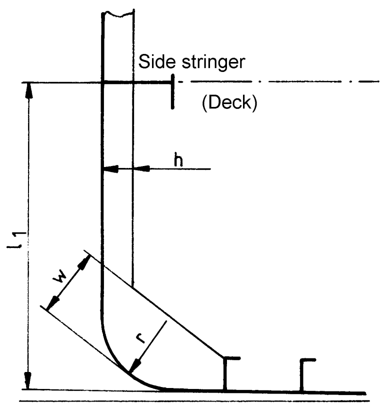


Fig. 7.1.2 Lower span of side frame in way of single bottom

7.2 Structural Arrangement

7.2.1 System of Framing

In the case of ships, where maximum slamming pressure on bottom acc. to 6.7.5, or slamming pressure on sides acc. to 7.4.5 exceeds 10 *T*, or increase of k_{wm} (see 15.5.2.1) acc. to 15.2.2.2, application of longitudinal side stiffeners by the bottom and strength deck is recommended.

Continuity of side longitudinals is to be maintained in the same way, and for the same areas along the ship, as required for bottom and deck longitudinals (see 6.2.2.2).

7.2.2 Side Girders

7.2.2.1 In the after peak, engine room and boiler room, side structure is to be strengthened by means of web frames at spacings not exceeding 5 frame spaces.

7.2.2.2 To ensure adequate transverse hull rigidity, transverse bulkheads or web frames connected in the same plane to deck transverses are to be fitted between decks.

7.2.2.3 In the fore peak below the deck arranged above the design waterline, platforms or side stringers and rows of stiffeners (panting beams) are to be fitted. The distance between side stringers or platforms (measured vertically) is not to exceed 2 m.

7.2.3 Openings in Side Shell

7.2.3.1 No openings are to be arranged in the sheer strake and in way of plating exposed to high shear stress. Round openings for side scuttles or for other purposes may be arranged within the area considered, if necessary. The openings are to have edge reinforcement according to 3.5.2. Openings in side shell are to be located more than twice the opening height below strength deck or termination of rounded sheer strake. The openings are to comply with the requirements of 3.5.

7.3 Scantlings of Structural Members

7.3.1 Plating

7.3.1.1 The thickness of the side plating is to be determined according to 13.2 and 13.4.

7.3.1.2 In ships of $L_0 \geq 100$ m, within the below-specified region, the thickness of side plating is also to be not less than:

$$t = 4s\sqrt[4]{\frac{D}{k^2 L_0}} + t_k\,, \quad \text{[mm]} \qquad (7.3.1.2)$$

s – spacing of frames supporting the side plating, [m];
D – displacement of ship at draught T, [t].

The region in question extends between a section aft of amidships where the breadth at the load waterline exceeds 0.9 B and a section forward of amidships where the load waterline breadth exceeds 0.6 B and has been taken from the lowest ballast waterline to $z = T + z_0$, [m] ($z_0 = 0.25\ T$ but not less than 2.3 m).

7.3.1.3 The thickness of the side plating in the forebody is to be checked additionally for slamming pressure in compliance with 7.4.2, if applicable.

7.3.2 Sheer Strake at Strength Deck

7.3.2.1 The breadth of sheer strake is not to be less than that determined from the formula:

$$b = 800 + 5L_0, \quad \text{[mm]} \qquad (7.3.2.1)$$

but need not exceed 1800 mm.

7.3.2.2 The thickness of sheer strake within $-0.25\ L_0 \le x \le 0.25\ L_0$ is not to be less than that determined from the formula:

$$t = \frac{t_1 + t_2}{2}, \quad \text{[mm]} \qquad (7.3.2.2)$$

t_1 – required side plating thickness, [mm];
t_2 – required strength deck plating thickness, [mm], where $t_2 \ge t_1$.

7.3.2.3 The thickness of sheer strake within $x < -0.4\ L_0$ and $x > 0.4\ L_0$ may be equal to that of the side plating within this area. Between the midship portion of the ship ($-0.25\ L_0 \le x \le 0.25\ L_0$) and the extreme portions ($x < -0.4\ L_0$ and $x > 0.4\ L_0$) the thickness varies linearly.

7.3.2.4 Where rounded sheer strake is applied at the strength deck, the curvature radius of cold rolled plates is not to be less than 15 t (t – plate thickness, [mm]).

7.3.2.5 Where end bulkhead of superstructure is located within $-0.25\ L_0 \le x \le 0.25\ L_0$ and the superstructure deck forms part of the strength deck, the thickness of sheer strake is to be increased by 30% on each side of this bulkhead over the lengths at least 3 m.

7.3.3 Stiffeners

7.3.3.1 The scantlings of transverse side frames in deep tanks, 'tween decks, machinery space and peaks are to be determined according to 13.5.

'Tween deck frames are the frames between the lowest deck or the lowest side stringers and the uppermost superstructure deck and between the collision bulkhead and the after peak bulkhead.

7.3.3.2 When calculating, according to 13.5, the section modulus of main frames with brackets at both ends, the following values of permissible stresses may be used:

$\sigma = 185\ k$ when external sea pressure p is used;
$\sigma = 165\ k$ when internal pressure p due to cargo, provisions and ballast is used.

These permissible stresses are applicable if effective brackets are fitted at both ends. The vertical arm length of effective brackets is not to be less than:

$0.12\ l$ – for the lower bracket,
$0.07\ l$ – for the upper bracket (l – span of the main frame, [m]).

The length of vertical arm of the lower bracket is to be measured from the upper edge of the floor plate.

Where the length l_w of the free edge of the bracket exceeds 40 t (t – bracket thickness), a flange or face plate of the width not less than 0.067 l_w is to be fitted.

7.3.3.3 The section modulus of main frame, calculated for end parts of the frame taking into account the cross-sectional area of the respective end brackets, is not to be less than that required in 13.5 with l equal to the total span of frame (excluding the end brackets) and with bending moment factor m equal to:
8 – for the lower end of the frame,
10 – for the upper end of the frame.

7.3.3.4 End brackets of main frames may be omitted, provided the frame is carried through the supporting structures and the section modulus, determined according to 13.5 assuming the total span l , is increased by 50%.

7.3.3.5 The assumed section modulus of the main frame is not to be less than that of the 'tween deck frame above.

7.3.3.6 The side frames supporting hatch end beams are to be reinforced to withstand additional bending moments from deck structure.

7.3.3.7 The section modulus of 'tween deck frames and peak frames is not to be less than that determined from the formula:

$$W = k_1\sqrt{\frac{L_0}{k}}\,, \quad [\mathrm{cm}^3] \qquad (7.3.3.7)$$

$k_1 = 4.0$ for 'tween deck frames,
$k_1 = 6.5$ for peak frames.

7.3.3.8 Side framing in the forebody is to be checked additionally for slamming pressure according to 7.4.3, if applicable.

7.3.3.9 The scantlings of panting beams in the forebody are to correspond to the requirements of 13.7.4.

7.3.4 Tripping Brackets

When the span of frames exceeds 5 m or the flange width is less than 1/20 of the span, a tripping bracket is to be fitted in the middle of the span. Within $x > 0.35$ L_0, except the fore peak, the tripping brackets are to extend to the adjacent frame. The vertical distance between tripping brackets is not to exceed 2.5 m. The thickness of the bracket is to be equal to frame web thickness or 10 mm, whichever is the lesser.

7.3.5 Simple Girders

7.3.5.1 The scantlings of web frames and side stringers supporting the frames are to be determined according to 13.5.

7.3.5.2 Cross ties may be regarded as effective supports for web frames when:
– the cross tie extends from side to side, or
– the cross tie is supported by other structures which may be considered sufficiently rigid, or
– the load condition may be considered symmetrical with respect to the cross tie.

7.3.5.3 Cross ties regarded as effective supports for web frame may be taken into consideration when determining the design span of the web frames, provided their arrangement meets the following requirements:
– for web frames with one cross tie:
the cross tie is located (0.36 ÷ 0.5) l_w from the lower end of web frame,
– for web frames with two cross ties:
the lower cross tie is located (0.21 ÷ 0.3) l_w from the lower end and the upper cross tie is located (0.53 ÷ 0.58) l_w from the lower end of web frame (l_w – span of web frame measured from the floor to the deck beam, [m]).

Web frames with more than two cross ties or with cross ties not located as given above will be specially considered by PRS.

The cross ties are assumed to be spaced evenly on side stringers.

7.3.5.4 Web frames in the machinery space and in peaks are to have the web height not less than that determined from the formula:

$$h = 2L_0 l, \quad \text{[mm]} \tag{7.3.5.4}$$

The height h need not be greater than:

$$h = 200 l, \quad \text{[mm]}$$

l – girder span, [m].

Girder flanges within the machinery space are to have a thickness not less than 35 l, [mm].

Girder flanges are to have a thickness not less than 1/30 of the flange width for symmetrical flanges and not less than 1/15 of the flange width when the flange is asymmetrical.

7.3.5.5 In transverse framing structures – in the region forward of the collision bulkhead and below the deck positioned above the design waterline – horizontal side stringers are to be arranged. The vertical spacing of these stringers is not to exceed 2 m.

The stringers are to be supported by rows of panting beams. The spacing of beams may be equal to two frame spacings. Intermediate frames are to be connected to stringers by means of brackets. Horizontal arms of brackets are to be of the length equal to at least half the breadth of the stringer webs.

Instead of panting beam rows, side web frames may be adopted. The spacing of the web frames is not to exceed 3 m. In the case of longitudinal side framing, the spacing of web frames is not to exceed 2.4 m.

The required value of the moment of inertia I_α of cross-section of panting beams (with effective plate flange, if provided) is to be determined according to 13.7.3. It may be also calculated using the simplified formula:

$$I_\alpha = 6k_1 T l^2 \text{, [cm}^4\text{]} \qquad (7.3.5.5)$$

k_1 = $\frac{A}{2.4}$, but not less than 1.0;

A – side plate area supported by the panting beam in question, [m^2];

l – span of the panting beam, [m].

7.3.6 Complex Girder System

The scantlings of girders being part of a complex system may be required to be based on direct stress analysis in compliance with the requirements of Chapter 14.

7.4 Strengthening of the Forebody

7.4.1 Application

The requirements of the present sub-chapter are applicable to all ships and cover the forebody within $z \geq T$, and along the ship to the section at 0.1 L_0 from FP abaft, with regard to the wave impact pressure.

In general, only ships with length $L_0 \geq 100$ m, greater service speed and large flare in the forebody will require the strengthening to be provided.

7.4.2 Shell Plating

7.4.2.1 The thickness of shell plating in way of the region in question is not to be less than that determined from formula 6.7.2.1-1, with impact pressure p_u determined according to 7.4.5.

7.4.2.2 Outside the bow region, the shell plating thickness is to be gradually reduced to the value required outside this region.

7.4.3 Scantlings of Stiffeners

7.4.3.1 The section modulus and cross-sectional area of the stiffener web of side longitudinals and transverse frames are to comply with the requirements of 6.7.3 taking the value of p_u as given in 7.4.5.

7.4.3.2 Outside the bow region, the scantlings of the stiffeners may be gradually reduced to the value required outside this region.

7.4.3.3 Tripping brackets (see 7.3.4) are to be applied where frame webs are not perpendicular to the side plating.

7.4.4 Other Requirements

7.4.4.1 Webs of web frames, stem horizontal brackets, side longitudinal stringers, decks and bulkheads in the forebody are to have a plate thickness not less than:

$$t = \frac{6.5 + 0.15\sqrt{p_u}}{\sqrt{k}} + t_k\,, \quad \text{[mm]} \qquad (7.4.4.1)$$

p_u – pressure as given in 7.4.5.

For the remaining symbols, see 7.4.4.4.

7.4.4.2 The spacing of stiffeners on girder web plates or decks near the shell plating is not to exceed:

$$s_n = 0.09\,t\,, \quad \text{[m]} \qquad (7.4.4.2)$$

t – thickness of deck plating or girder web in question, [mm].

7.4.4.3 The net section modulus of girders in the bow region (after deduction of corrosion allowances) is not to be less than that determined from the formula:

$$W = \frac{0.15\,l^2\,b\,p_u}{k}\,, \quad \text{[cm}^3\text{]} \qquad (7.4.4.3)$$

For symbols, see 7.4.4.4.

7.4.4.4 The web cross-section area at each end of a girder is not to be less than that determined from the formula:

$$A_s = \frac{0.02\,l\,b\,p_u}{k} + 10\,h_w\,t_k\,, \quad \text{[cm}^2\text{]} \qquad (7.4.4.4)$$

p_u – pressure determined according to 7.4.5;
h_w – girder web height, [m];
l – girder span, [m];
b – breadth of plating supported by a girder, [m];
t_k – corrosion allowance (see 2.5), [mm];
k – material factor.

7.4.5 Impact Pressure

The design impact pressure acting on forebody side plating is to be determined from the formula:

$$p_u = c\left(2.2 + 1.5\,\mathrm{tg}\,\alpha\right)\left(0.4v\sin\beta + 0.6\sqrt{L_0}\right)^2, \quad \text{[kPa]} \qquad (7.4.5\text{-}1)$$

$$c = 0.18\left(C_W - 0.5h_0\right), \text{ but not more than 1.0;} \qquad (7.4.5\text{-}2)$$

C_W – wave coefficient – see Chapter 17;
h_0 – vertical distance of the point in question from the design waterline, [m];
v – speed of the ship;
L_0 – design length of the ship;

α – flare angle measured in plane perpendicular to the waterline in the point in question – see Fig. 7.4.5;

β – angle measured in the plane of waterline with the point in question, between the centre line and the line tangent to the plating in the point in question – see Fig. 7.4.5.

The angle α may be determined from the formula:

$$\mathrm{tg}\alpha = \frac{a_1 + a_2}{z_w} \qquad (7.4.5\text{-}3)$$

for a_1, a_2, z_w – see Fig. 7.4.5.

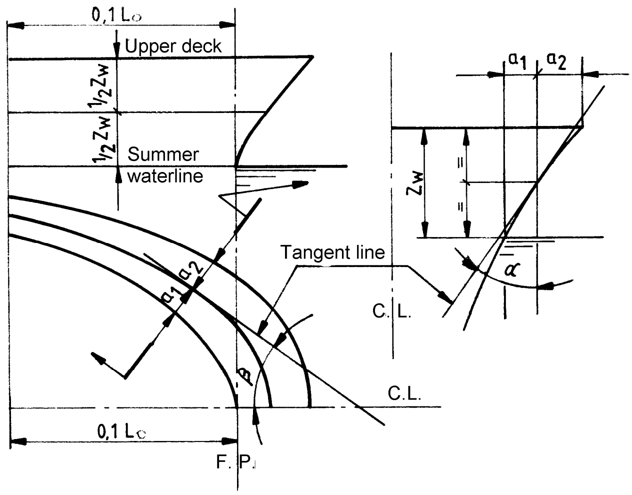


Fig. 7.4.5 Side plating flare angle

Note: If the values of a_1 and a_2 differ considerably, the pressure p_u is to be determined for several waterlines.

8 DECKS

8.1 General

8.1.1 Application

8.1.1.1 The requirements of the present Chapter apply to deck and platform structures according to the definition given in A/2.4.

8.1.1.2 Additional requirements regarding the decks intended for the carriage of vehicles are given in Chapter C/10, and for helidecks in Chapter C/9.

8.2 Structural Arrangement

8.2.1 System of Framing

Ships with length $L_0 > 100$ m are to have longitudinal stiffening system in the strength deck out of hatchway openings. In deck areas between hatches preferable is transverse system of framing.

8.2.2 Deck Longitudinals

When the strength deck is longitudinally stiffened it is recommended that the longitudinals pass continuously through all transverse members within $-0.25\ L_0 \le x \le 0.25\ L_0$.

In ships with 40 m $< L_0 \le 100$ m, the longitudinals may be cut at transverse members within $-0.25\ L_0 \le x \le 0.25\ L_0$; in that case continuous brackets crossing the members and connecting the ends of the longitudinals are to be fitted or the structure continuity is to be otherwise provided;

In ships with $L_0 \ge 40$ m outside $-0.25\ L_0 \le x \le 0.25\ L_0$, and in the ships with $L_0 \le$ 40 m, the longitudinals may be cut at transverse members and welded or connected to them by brackets.

8.2.3 Deck Structure between Hatches

8.2.3.1 Where deck longitudinals are used in deck areas between hatches, the plate thickness is to be increased to ensure transverse loads' stability, or transverse intercostals are to be fitted.

8.2.3.2 Transverse beams are to be extended to the second longitudinal from the hatch side. Where this is impracticable, transverse beams are to be extended to the second longitudinal by means of intercostals or brackets.

8.2.3.3 The stiffening of the upper part of a plane transverse bulkhead is to ensure sufficient stability of the all structure under transverse compressive loads resulting from compressive loads on sides (see also 8.4.1).

8.3 Scantlings of Structural Members

8.3.1 Plating

8.3.1.1 The thickness of the deck and platform plating is to be determined according to 13.2 and 13.4. In addition, the plating of decks forming boundaries of tanks is to comply with the requirements for watertight bulkheads at heights corresponding to those at which the decks are located.

8.3.1.2 The thickness of the stringer plate in way of the strength deck is not to be less than that of the adjacent deck plating. If, in the ship with $L_o > 65$m, the end bulkhead of a superstructure is located on the strength deck within $-0.25\ L_0 \le x \le 0.25\ L_0$, the stringer plate thickness is to be increased by 20% for a length of 3 m on each side of the superstructure end bulkhead.

8.3.1.3 The breadth of stringers plate or strakes in way of longitudinal bulkhead subjected to hull longitudinal bending, which are to be of steel grade B, D or E, is not to be less than that determined from the formula:

$$b = 800 + 5L_0, \quad [\text{mm}] \qquad (8.3.1.3)$$

but need not exceed 1800 mm.

8.3.2 Stiffeners

The scantlings of beams and deck longitudinals of decks and platforms are to be determined according to 13.5. Additionally, these scantlings are to comply with the relevant requirements for stiffeners of watertight bulkheads in the case of decks and platforms forming tank boundaries.

8.3.3 Scantlings and Arrangement of Deck Girders

8.3.3.1 The scantlings of such simple girders as: deck stringers, deck transverses and hatchway end beams, as well as hatch coamings regarded as deck girders are to comply with the requirements of sub-chapter 13.6.

8.3.3.2 The requirements regarding scantlings of hatch side cantilevers are given in 8.3.5.

8.3.3.3 The longitudinal girders in a deck or platform being the top of a tank are to be arranged in line with the vertical girders of transverse bulkhead.

The flange area is to be at least 1/7 of the sectional area of the web plate and the flange thickness is to be at least 1/30 of the flange width.

8.3.3.4 Transverse girders are to be fitted in the lowest deck in the engine room in line with web frames. The depth of transverse girders is to be at least 50% of the height of web frames, whereas the web thickness and face plate scantlings are to be equal to the appropriate scantlings of the web frame.

8.3.4 Complex Girder Systems

The scantlings of girders being part of complex girder systems may be required to be based on a direct stress analysis in compliance with the requirements of Chapter 14.

8.3.5 Scantlings of Hatch Side Cantilevers

8.3.5.1 The requirements of the present sub-chapter apply to the scantlings of hatch side cantilevers, including web frames which may be regarded as simple girders (see Fig. 8.3.5.1).

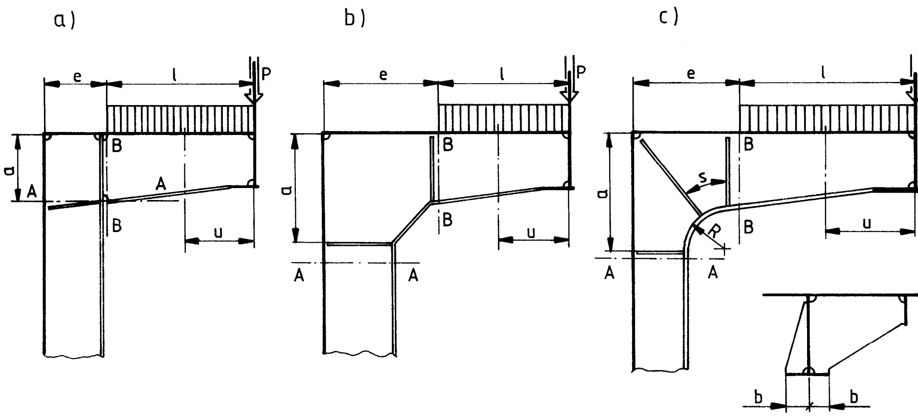


Fig. 8.3.5.1 Hatch side cantilevers

The stress analysis according to Chapter 14 is to be carried out where other structural solutions are applied.

8.3.5.2 For the purpose of the present sub-chapter, the following symbols have been used:

a, e – corner dimensions (see Fig. 8.3.5.1), [m];
b_e – effective breadth of face plate, [cm];
b – half of actual face plate breadth, [cm];
l – span of hatch side cantilever, [m];
P – concentrated force acting in way of intercrossing of the cantilever with the hatch coaming due to the load acting on the hatch cover and on the transversely stiffened deck, [kN];
Q – distributed load from cargo acting on longitudinally stiffened deck:
$Q = p\, l\, b_0$, [kN];
b_0 – breadth of the loaded area equal to the spacing of cantilevers, [m];
p – design pressure due to loading calculated according to Chapter 16, [kPa];
$Q = 0$ for transversely stiffened deck;
u – distance of the considered cantilever cross-section from its end (see Fig. 8.3.5.1), [m].

8.3.5.3 The section modulus of a cantilever and a web frame (sections A-A and B-B, see Fig. 8.3.5.1) is not to be less than:

$$W = \frac{6}{k} l \left(P + 0.5Q\right), \quad [\text{cm}^3] \qquad (8.3.5.3)$$

8.3.5.4 Effective breadth of the flange b_e is to be determined as follows:
– for not rounded connection of the cantilever with the web frame (see Fig. 8.3.5.1 a, b):

$$b_e = 2b, \quad [\text{cm}] \qquad (8.3.5.4\text{-}1)$$

– for the rounded connection of the cantilever with the web frame (see Fig. 8.3.5.1 c):

$$b_e = 2Kb, \quad [\text{cm}] \qquad (8.3.5.4\text{-}2)$$

$$K = 1 - k_1\left(1 - \frac{2}{c+2}\right) \qquad (8.3.5.4\text{-}3)$$

k_1 – coefficient taken from Table 8.3.5.4;
c – coefficient determined from the formula:

$$c = \frac{b^2}{R\,t_m} \qquad (8.3.5.4\text{-}4)$$

R – radius of curvature, [cm];
t_m – the flange thickness; $t_m \ge \frac{b}{10}$, [cm] is to be taken.

Table 8.3.5.4
Values of k_1 coefficient

s/b	k_1
$0 < s/b \le 2$	0.1 *s/b*
$2 < s/b \le 4$	0.1 (3 *s/b* – 4)
$4 < s/b \le 8$	0.05 (*s/b* + 12)

s – spacing of stiffeners according to Fig. 8.3.5.1, measured along the edge of the face plate, [cm].

8.3.5.5 The breadth of the effective flange of the deck and shell plating is to be taken as 0.4 l . The assumed breadth is not to be greater than the spacing between the cantilevers and the distance e (see Fig. 8.3.5.1).

8.3.5.6 The net sectional area of the cantilever web is not to be less than:

$$A_s = \frac{0.12}{k}\left(P + Q\frac{u}{l}\right), \quad [\text{cm}^2] \qquad (8.3.5.6)$$

8.3.5.7 The thickness of the corner web plate in way of the sections A-A and B-B in Fig. 8.3.5.1 is not to be less than:

$$t = \frac{0.012}{k}\left(P + 0.5Q\right)\frac{l}{a\,e}, \quad \text{[mm]} \qquad (8.3.5.7)$$

The corner web plate made in compliance with a and b (Fig. 8.3.5.1) is to be additionally strengthened if the dimensions a and e exceed 70 t .

8.4 Additional Requirements

8.4.1 Transverse Strength of Deck between Hatches

In ships with large hatch openings, it is to be checked that the effective deck cross-section area between hatches is sufficient to withstand the transverse load imposed on the ship's sides. Bending and shear stresses may also arise as the result of loading on the transverse bulkhead adjacent to the deck area and also as the result of displacements due to torsion in the hull girder.

Reinforcements to reduce the additional stresses will be considered by PRS in each particular case. The effective cross-section area of the deck structure between adjacent hatches is composed of cross-sections areas of:

– deck plating,
– transverse beams,
– transverse deck girders,
– hatch end beams (after separate consideration),
– transverse bulkhead (plane or horizontally corrugated) down to base of top wing tank or to 0.15 H from deck, whichever is the lesser.

Corrosion allowances are to be deduced when calculating the effective cross-section area.

The compressive stress is not to exceed 120 k , [MPa] nor 80% of the critical buckling stress of the deck and bulkhead plating. The buckling strength of stiffeners and girders is to be also checked.

8.4.2 Strengthening at Deck Break

The strengthenings at deck break will be specially considered by PRS in each particular case.

8.4.3 Supporting of Lifting Appliances

8.4.3.1 Masts and columns are to have effective supports and their design is to provide the connection with at least two decks or with one deck and a masthouse of sufficiently strong structure.

8.4.3.2 The deck is to be sufficiently stiffened and strengthened in those places where standing rigging, guys and topping lifts are fitted.

8.4.3.3 Strengthening of the deck structure by girders, supported additionally by pillars, if necessary, is to be provided under the longitudinal girders of seatings of gear arranged on the deck. Those strengthenings will be specially considered by PRS in each particular case.

8.5 Openings in Decks

8.5.1 General

8.5.1.1 The width of openings of single cargo hatches is not to exceed 0.6 of the ship's breadth in way of the opening. Where the opening breadth is greater and in the case of double and triple hatches, the deck structure will be specially considered by PRS with particular attention paid to the hatch corners and their strengthenings.

8.5.1.2 Openings in decks other than hatch openings are to comply with the following requirements:

- as far as possible, openings in the strength deck within $-0.3\ L_0 \le x \le 0.3\ L_0$ are to be arranged between the hatches;
- openings in strength deck between the ship's side and line of hatch openings are to be well clear of the hatch corners and side;
- openings in the remaining areas and decks are to be sufficiently clear of the corners of hatch openings and areas where increased stresses may occur;
- the requirements of sub-chapter 3.5 regarding the performance, arrangement and strengthening of openings are to be complied with.

8.5.2 Hatchway Corners

8.5.2.1 The shape of hatch opening corner within $-0.3\ L_0 \le x \le 0.3\ L_0$ is to comply with the following requirements:

- where a corner of circular shape is applied, its radius is not to be less than:

$$R = 0.03\left(1.5 + \frac{a}{b}\right)\left(B_1 - b\right), \quad [\text{m}] \qquad (8.5.2.1\text{-}1)$$

b – breadth of hatchway, [m];
B_1 – breadth of the ship in way of the considered opening, [m];
a – distance between transverse edges of adjacent hatchways (the width of "cross deck structure" between hatchways), [m].
It may be taken that:

$$\frac{a}{b} \le 1 \quad \text{and} \quad 7.5 \le \left(B_1 - b\right) \le 15\,;$$

- where a corner with double curvature is applied, the radius may be reduced, the amount of this reduction being specially considered by PRS;
- where a corner of elliptical shape is applied, the transverse extension of curvature is not to be less than that determined from the formula:

$$d_y = 0.025\left(1.5 + \frac{a}{B_1}\right)\left(B_1 - b\right), \quad [\text{m}] \qquad (8.5.2.1\text{-}2)$$

8.5.2.2 The radius of curvature in hatchway openings in the remaining areas of the strength deck and the second deck located above 0.7 *H* may be by 50% less than that calculated from formula 8.5.2.1-1, but it is not to be less than 0.2 m.

8.5.2.3 The radius of curvature in hatchway openings on decks and platforms other than those specified above and on the upper deck in ships with $L_0 \leq 40$ m may be equal to 0.15 m.

8.5.3 Deck Strengthening in Way of Hatch Corners

8.5.3.1 Where hatch corners of circular shape are applied, the thickness of deck plates in strength deck in the area of hatch corners is to be increased by 25% in relation to the thickness required for this area.

8.5.3.2 The longitudinal extension of the thicker plating beyond the hatchway edge is not to be less than 1.5 *R* in fore and aft direction, whereas the transverse extension is not to be less than 2 *R* (for *R* – see formula 8.5.2.1-1).

8.5.3.3 The butt 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.

8.6 Coamings

8.6.1 General

8.6.1.1 The requirements regarding the coaming heights are covered by *Part III – Hull Equipment*.

8.6.1.2 Continuous, as well as non-continuous longitudinal hatchway coamings, if extended by continuous longitudinal deck girders, are to be made of steel of the same grade as the deck structure.

8.6.1.3 The upper edges of cargo hatchway coamings are to be smooth.

8.6.2 Structure of Provision Stores Hatchway Coamings

8.6.2.1 Vertical plates of longitudinal coamings are to be extended below the deck to the depth equal to at least the depth of deck beam sections.

Where the longitudinal coaming does not form a part of girder structure, its part located below the deck is to be extended by at least two frame spacings outside the hatch end beams.

8.6.2.2 Where vertical plates of the hatch transverse coaming are not in line with the hatch end beam, the considered plates are to be extended under the deck by at least three beam spacings outside the longitudinal hatch coamings.

8.6.2.3 Where longitudinal coamings act as deck girders, they are to be extended under the deck and duly connected to the hatch end beam. The diamond plates are to be fitted in way of junction.

8.6.2.4 Ends of side coamings at the hatchway corners on strength deck are to be bent along the corner curvature and butt welded to the transverse coamings, or longitudinal and transverse coamings are to be extended with use of brackets outside the corners.

The brackets are to provide a smooth transition of coamings to girders under the deck.

8.6.2.5 Where the web plate of a hatch side coaming does not exceed 0.6 m in height, it is to be stiffened with vertical stiffeners at each frame or at spacings of about 60 times the web thickness. Tripping brackets are to be fitted on every second frame and the upper edge of the coaming is to be strengthened by a stiffener.

8.6.2.6 Hatchway coamings extending 0.6 m and more above the deck are to be stiffened by a horizontal stiffener not more than 0.25 m from the upper edge of the coaming. Where the coaming length exceeds 3 m, coaming brackets are to be fitted at distances not exceeding two frame spacings between the horizontal stiffener and the deck.

Strengthening of coamings with the height exceeding 0.9 m and the coamings of power operated hatch covers will be specially considered by PRS.

8.6.3 Scantlings of Hatchway Coamings

8.6.3.1 The scantlings of coamings acting as deck girders or hatch end beams are to comply with the requirements given in 8.3.3.

8.6.3.2 Hatchway coamings of holds intended for ballast or liquid stores are to satisfy the requirements for the tank bulkheads given in 9.3.

8.6.3.3 The thickness of hatchway vertical coamings plate in ships with length $L_0 > 60$ m is not to be less than 11 mm.

8.6.3.4 Stiffeners, brackets and coamings are to be able to withstand the local forces set up by the clamping devices and/or the handling facilities necessary for securing and moving the hatch covers, as well as mass forces from the stores stowed on the hatch covers (see also *Part III – Hull Equipment*).

8.6.4 Ventilator Coamings

8.6.4.1 The thickness of ventilator coamings situated on the freeboard deck and on the exposed superstructure decks within $x \geq 0.25\, L_0$ is not to be less than that determined by the formula:

$$t = 0.01d + 5, \quad \text{[mm]} \qquad (8.6.4.1)$$

d – internal diameter or the length of the greater side in the case of rectangular coaming, [mm].

The thickness t is not to be less than 7 mm and it need not exceed 10 mm.

The thickness of coamings situated on the decks of the first tier in superstructures within $x < 0.25\, L_0$ may be reduced by 10% as compared to that required for the coamings on the freeboard deck.

8.6.4.2 Where the thickness of the deck plating is less than 10 mm, the plate of the length and breadth not less than twice the diameter or twice the length of the greater side of the coaming and of thickness not less than 10 mm is to be provided in way of the coaming.

Where suitable connection between the coamings and deck structure is provided, the above-mentioned plate is not required.

8.6.4.3 Where the ventilator coaming is higher than 900 mm, it is to be connected to the deck by means of brackets.

8.6.5 Coamings of Companion-hatches and Skylights

The structure of the coamings of companion-hatches and skylights is to be of the strength equivalent to that of cargo hatches; the thickness of coamings is not to be taken less than 7 mm, but need not be greater than that of the deck at the coaming.

8.7 Pillars

8.7.1 Arrangement and Attachment of Pillars

8.7.1.1 The pillar axis in ‘tween deck spaces and stores spaces are normally to be fitted in the same vertical line. Deck longitudinal and transverse girders in way of pillars are to be strengthened.

8.7.1.2 A doubling plate on the inner bottom or deck plating under the heel of a pillar of more than 125 mm in diameter is to be fitted (if the end brackets of the pillar are not provided). The doubling plate is to be welded continuously at its circumference. The thickness of the doubling plate is not to be less than:

$$t = \frac{P}{245} + 10, \quad \text{[mm]} \qquad (8.7.1.2)$$

P – nominal axial force in the pillar according to 13.7, [kN].

The diameter of the doubling plate is to be by 6 t greater than that of the pillar.

8.7.1.3 The ends of heavily loaded pillars and those exposed to considerable dynamic loads, pillars of diameter exceeding 350 mm, as well as all pillars of non-circular cross-section are to be fastened by means of brackets fitted above or under the deck, or in other equivalent way (conical inserts), irrespective of doubling plates, so as to ensure transfer of load between the pillars and to the structure of decks or inner bottom.

8.7.2 Scantlings of Pillars

8.7.2.1 Cross-section area of a pillar is to be determined according to 13.7.

8.7.2.2 The thickness of walls in tubular pillars is not to be less than that determined from the formula:

$$t = \frac{d_z}{50} + 3.5, \quad [\text{mm}] \qquad (8.7.2.2)$$

and is not to be less than 6 mm.
d_z – outer diameter of the pillar, [mm].

8.7.2.3 The web thickness of section built pillars is not to be less than that determined from the formula:

$$t = \frac{h_s}{50}, \quad [\text{mm}] \qquad (8.7.2.3)$$

and is not to be less than 6 mm.
h_s – height of the cross-section of the pillar web plate, [mm].

8.7.3 Pillars in Tanks

8.7.3.1 Where the hydrostatic pressure may induce the tensile stress in pillars, the pillar sectional area is not to be less than that determined from the formula:

$$A_p = 0.07 F_p p_p, \quad [\text{cm}^2] \qquad (8.7.3.1)$$

F_p – deck area supported by pillars, [m^2];
p_p – design pressure giving tensile stress in pillars, [kPa].

8.7.3.2 Pillars in tanks are to be made of plates or open sections.

8.7.3.3 End brackets are to be fitted instead of end doubling plates specified in 8.7.1.2.

8.8 Deck Strengthening for Containers

8.8.1 The Deck Structure in the Area of Containers

8.8.1.1 In the deck structure intended for stowage of containers, adequate, strong system of stiffeners or girders, in areas of lashing sockets and under lashing eyes used for containers lashing, is to be provided.

8.8.2 Design Loads

8.8.2.1 Permissible values masses of containers are to be specified in the *Loading Manual* (see 15.14).

Unless otherwise specified in the *Loading Manual*, the maximum mass of containers is to be taken as follows:
– 24 t – 20’ container;
– 30.5 t – 40’ container.

8.8.2.2 When determining dynamic loads from containers (inertial forces), possible combinations of vertical, transverse and longitudinal loads are to be considered according to principles in 17.6.8.

It may be assumed that transverse and longitudinal loads do not act simultaneously.

Containers, the side walls of which will be exposed to wind, are to be considered for a wind force, which may be taken as follows:

P_W = 17.5 kN for 20' containers,

P_W = 35.0 kN for 40' containers.

Horizontal dynamic loads are to be considered in combination with the wind force P_W.

8.8.3 Strength of stiffening system in container stowage area is to be checked for loads assumed in 8.8.2.2 in line with methods required in Chapter 14, applying permissible stresses values specified there.

9 BULKHEADS

9.1 General

9.1.1 Application

The requirements of the present Chapter apply to bulkhead structures and their arrangement in compliance with the definition given in A/2.5.

9.1.2 Definitions

L_F – the length of the ship – 96% of the total length of the ship measured on a waterline plane equal to 0,85 moulded depth of the hull, or length measured on that plane from the fore edge of the stem to the axis of the rudderstock (to the transom – for ships without classic rudders), whichever is greater. If a shape of the ships' bow or stern differs from usually applied, the length L_F will be specially considered by PRS.],

T_F – ship draught equal to 0.85 H_F, [m],

H_F – the least moulded depth measured to the freeboard deck, [m],

δ_F – hull block coefficient corresponding to T_F draught,

$$\delta_F = \frac{V_F}{L_F B\, T_F} \tag{9.1.2}$$

FP_F – fore perpendicular defined for L_F waterline.

h_N – height of superstructure, [m].

V_F – moulded volume of submerged part of the ship corresponding to T_F draught, [m].

9.2 Subdivision

9.2.1 General Requirements

9.2.1.1 The requirements of *Part IV – Stability and Subdivision* applicable to subdivision of a hull into watertight compartments are to be complied with.

9.2.1.2 The following transverse watertight bulkheads are to be fitted in all ships:

- collision bulkhead,
- after peak bulkhead,
- bulkheads at each end of the machinery space (the aft bulkhead of it may also act as an after peak bulkhead).

For ships without longitudinal bulkheads, the total number of watertight transverse bulkheads is not to be less than that given in Table 9.2.1.2.

The distance between the adjacent bulkheads is not to exceed 30 m; an increase in this distance will be specially considered by the PRS in each particular case.

After special consideration of the arrangement and strength by the PRS, the number of watertight bulkheads may be reduced.

Table 9.2.1.2
Number of transverse watertight bulkheads

Ship length L_F, [m]	Machinery space location	
	Aft [1)]	Elsewhere
$L_F \le 65$	3	4
$65 < L_F \le 85$	4	4
$85 < L_F \le 105$	4	5
$105 < L_F \le 125$	5	6
$125 < L_F \le 145$	6	7
$145 < L_F \le 165$	7	8
$165 < L_F \le 190$	8	9
$L_F > 190$	As agreed with PRS	

[1)] The after peak bulkhead forms the after boundary of the machinery space.

9.2.1.3 Location of the transverse bulkheads or partial bulkheads under superstructures or deckhouses end bulkheads, as well as under crane masts, heavy equipment and the ship's armament is recommended.

The said bulkheads are to be of adequate strength and rigidity to withstand static and dynamic loads from the supported members.

9.2.2 Position of Collision Bulkhead

9.2.2.1 The distance l_c from the perpendicular FP_F to the collision bulkhead is to be taken between the following limits:

$$\left.\begin{array}{ll} \text{for } L_F < 200 \text{ m:} & 0.05L_F - l_r \\ \text{for } L_F \ge 200 \text{ m:} & 10 - l_r \end{array}\right\} \le l_c \le 0.08L_F - l_r, \quad [\text{m}] \qquad (9.2.2.1)$$

where:

– for ships with ordinary bow shape:
$l_r = 0$;

– for ships having any part of the underwater body extending forward of FP_F,
l_r is to be taken as the smallest of:
$l_r = 0.5\ l_b$, [m],
$l_r = 0.015\ L_F$, [m],
$l_r = 3.0$, [m],
where l_b is determined as shown in Fig. 9.2.2.1.

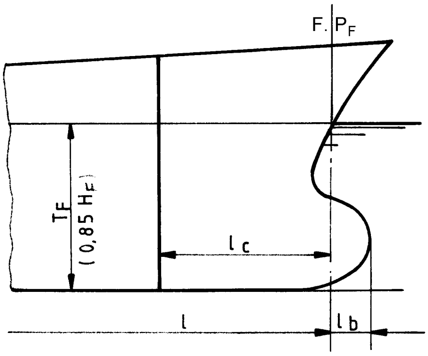


Fig. 9.2.2.1 Position of collision bulkhead

9.2.2.2 Steps or recesses in the collision bulkhead are also covered by the above requirements.

9.2.2.3 In ships having a visor or doors in the bow and a sloping loading ramp forming a part of the collision bulkhead above the upper deck, that part of the closed ramp which is more than 2.3 m above the freeboard deck may extend forward of the limits specified in 9.2.2.1 (see Fig. 9.2.2.3). The condition expressed by formula 9.2.2.1 is to be complied with.

The ramp is to be arranged for weathertight closing over its entire length.

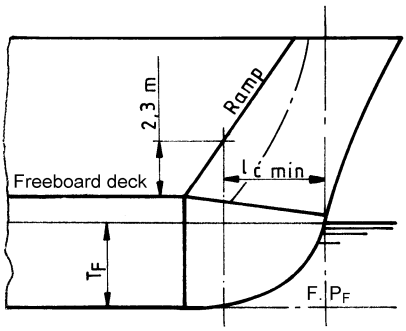


Fig. 9.2.2.3 Collision bulkhead with a ramp

9.2.2.4 Upon agreement with PRS, the distance of the collision bulkhead from FP_F may be increased with respect to that determined in 9.2.2.1 if emergency waterline is in each case below the freeboard deck after flooding the forepeak.

9.2.3 Vertical Extension of Watertight Bulkheads

9.2.3.1 All watertight bulkheads are to extend to the upper deck. After peak bulkhead may terminate at the first watertight deck above the design waterline – provided that the deck, in area of the bulkhead in question and abaft, is watertight.

9.2.3.2 For ships with a continuous deck below the freeboard deck and where the draught is less than the depth to the second deck – all bulkheads, except the collision bulkhead, may terminate at the second deck – provided that all stability and subdivision criteria specified in *Part IV – Stablity and Subdivision* are complied with. In such cases, however, the engine casing between the second and upper deck is to be arranged as a watertight structure and the second deck is to be watertight outside the casing above the engine room.

9.2.3.3 For ships having complete or long forward superstructures, the collision bulkhead is to extend to the next deck above the freeboard deck. The extension need not be fitted directly over the bulkhead below, provided the requirements of 9.2.1 are complied with and the part of the freeboard deck forming the step is made watertight.

9.2.4 Cofferdams

9.2.4.1 Cofferdams are to be arranged to separate:
- fuel tanks from accommodation, duty and cooled spaces and fresh water tanks, lubricating oil and vegetable oil tanks;
- oil tanks from accommodation, duty and cooled spaces, fuel and fresh water tanks;
- fresh water tanks from fuel, lubricating oil and sewage tanks.

The width of vertical cofferdams is to be not less than 0.6 m and the height of the horizontal cofferdams not less than 0.7 m, unless specified otherwise.

Cofferdams are to be accessible to survey and repairs. The cofferdam forward of the collision bulkhead (forepeak) is not considered as cofferdam.

9.2.4.2 Where fuel oil tanks have to be located in the machinery space or in close vicinity, the tanks are to be so designed as to avoid direct interaction with their bulkheads high temperatures generated by possible fire in machinery space.

9.2.5 Minimum Bow Height

9.2.5.1 The required bow height H_b, as the vertical distance at the forward perpendicular FP_F from the design waterline to the top of the exposed deck at side, is given by the formula:

$$H_b = 56\,L_F\left(1-\frac{L_F}{500}\right)\frac{1.36}{\delta_F+0.68}, \quad \text{[mm]} \qquad (9.2.5.1)$$

δ_F – block coefficient, not to be taken less than 0.68.

9.2.5.2 Where the bow height is obtained by fitting a forecastle, such forecastle is to extend from the stem to a transverse section of hull at least 0.07 L_F from fore perpendicular FP_F abaft.

9.2.5.3 Where the bow height is obtained by increasing the sheer of the upper continuous deck, the sheer is to extend from the stem to a transverse section of hull at least 0.15 L_F from fore perpendicular FP_F abaft.

9.2.6 Gastight Bulkheads

Gastight bulkheads are to be arranged and designed in compliance with provisions set out in C/2 and C/4.

9.3 Structural Arrangement

9.3.1 General Requirements

9.3.1.1 The peak tanks are to have centre line wash bulkheads when the breadth of the tank exceeds 2/3 *B*.

9.3.1.2 In ships with machinery space situated amidships, a watertight shaft tunnel is to be arranged. The PRS may accept that the shaft tunnel is omitted provided the shafting is otherwise effectively protected. Bearings and stuffing boxes are to be accessible.

9.3.1.3 The stern tube is to be fitted in the watertight compartment. The stern tube stuffing box is to be fitted in the watertight shaft tunnel or in other watertight space separated from the stern tube compartment.

9.3.1.4 Openings may be arranged in watertight bulkheads if they and their closing appliances comply with the requirements of *Part III – Hull Equipment*.

9.3.2 Structure of Longitudinal Bulkheads

Within $-0.25\ L_0 \le x \le 0.25\ L_0$, in the areas 0.15 *H* above the bottom and 0.15 *H* below the strength deck, continuity of bulkhead longitudinals is required for bottom and deck longitudinals, respectively.

9.3.3 Corrugated Bulkheads

9.3.3.1 Transverse and longitudinal tank and hold bulkheads may be corrugated.

The lower and upper parts of longitudinal bulkheads with horizontal corrugation are to be plane for a distance not less than 0.13 *H* measured from the bottom and deck, respectively.

The transverse corrugated bulkheads with vertical corrugations are to be plane for a distance not less than 0.08 *B* measured from the ship sides.

9.3.3.2 Design spacings of stiffenings in corrugated bulkheads are assumed as follows (see Fig. 9.3.3.2):

– for plate thickness calculation, the greater of the values:

$s = 1.05\ s_2$ or $s = 1.05\ s_3$, [m] – in general,

$s = s_2$ or $s = s_3$, [m] – where the web plates are perpendicular to the attached plating;

– $s = s_1$ for corrugated bulkheads required section modulus calculations.

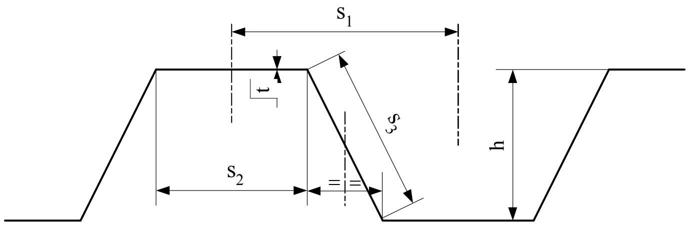


Fig. 9.3.3.2 Corrugated bulkhead

9.4 Scantlings of Structural Members

9.4.1 Plating

9.4.1.1 The thickness of plating in watertight, wash and tank bulkheads is to be determined according to 13.2 and 13.4.

9.4.1.2 Increase of the plating thickness of after peak bulkhead or fitting of doubling plate in way of shaft stuffing box may be required.

9.4.1.3 Unless the buckling strength is proved satisfactory by direct stress analysis, the corrugated bulkheads plating thickness is not to be less than:

$$t = \frac{s_2}{0.05}, \quad \text{[mm]} \quad \text{if} \quad \frac{s_2}{s_3} = 0.5 \qquad (9.4.1.3\text{-}1)$$

$$t = \frac{s_2}{0.07}, \quad \text{[mm]} \quad \text{if} \quad \frac{s_2}{s_3} \geq 1.0 \qquad (9.4.1.3\text{-}2)$$

(for s_2, s_3 – see Fig. 9.3.3.2).

The minimum required values of thickness t for intermediate values s_2/s_3 are to be obtained by linear interpolation..

Where section modulus of corrugated bulkhead is greater than the required value, the bulkhead thickness may be reduced by multiplying the required thickness by the following factor:

$$\sqrt{\frac{W\,required}{W\,actual}} \qquad (9.4.1.3\text{-}3)$$

9.4.2 Stiffeners

9.4.2.1 The scantlings of the vertical and horizontal stiffeners and of the elements of corrugated bulkheads are to be determined in compliance with 13.5.

9.4.2.2 Stiffeners transferring the axial compression loadings are to comply with the requirements of 13.7.3.

9.4.3 Simple Girders

The scantlings of horizontal and vertical girders in longitudinal and transverse bulkheads are to be determined according to 13.6.

Where the bulkhead girders transfer the axial compression loadings, the scantlings of their members are to comply with the requirements of 13.7.3.

9.4.4 Complex Girder Systems

The scantlings of bulkhead girders being part of complex girder systems may be required to be based on a stress analysis in compliance with the requirements of Chapter 14.

9.5 Additional Requirements

9.5.1 Shaft Tunnel

9.5.1.1 The scantlings of shaft tunnel girders are to comply with the requirements applied to bulkheads, but the thickness of the curved top plating may be taken as 90% of that required for the plane plating with the same stiffener spacing.

9.5.2 Supporting Bulkheads

9.5.2.1 Bulkheads supporting decks are to be regarded as pillars and are to comply with the requirements of 13.7.3. The radius of gyration of the stiffener cross-section is to be calculated including the effective flange width of bulkhead plating equal to 40 t (t – bulkhead plate thickness).

9.5.2.2 The plate thickness is not to be less than 6.5 mm.

9.5.2.3 The depth of corrugations on corrugated bulkheads is not to be less than 100 mm in ‘tween decks.

10 SUPERSTRUCTURES, DECKHOUSES, SPONSONS AND BULWARKS

10.1 General

10.1.1 Application

The requirements of the present Chapter apply to superstructure end bulkheads, deckhouse sides and ends, casings and bulwarks and sponsons.

Sides of superstructures are covered by the requirements of Chapter 7 (Side Structures), whereas decks of deckhouses and superstructures are covered by the requirements of Chapter 8 (Decks).

10.1.2 Explanations

Long deckhouse – deckhouse having not less than 0.2 L_0 of its length within 0.4 L_0 amidships.

Short deckhouse – deckhouse that cannot be defined as a long deckhouse.

Tier – space between the successive decks of a superstructure or deckhouse; tiers are counted from the upper deck.

10.1.3 Definitions

l – stiffener span, [m], determined according to 3.2.1;
s – stiffener spacing, [m];
p – design pressure, [kPa].

10.2 Structural Arrangement

10.2.1 Structural Continuity

10.2.1.1 In superstructures and deckhouses, particularly those situated aft, the front bulkhead is to be in line with a transverse bulkhead below the deck or is to 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 walls are to be located in line with tank bulkhead or girders in the hull structure and are to be in line in successive tiers of erection.

Where such structural arrangement in line is not possible, other effective support is to be applied.

10.2.1.2 Sufficient transverse strength and stiffness of superstructures and deckhouses is to be assured by means of transverse bulkheads or girder structures.

10.2.1.3 Where sides of the superstructure are in line with ship's sides, the plating of the sides is to be extended beyond the end bulkhead of the superstructure and is to transit smoothly to the sheer strake. The transition is to be free of local discontinuities. A substantial stiffener is to be fitted at the free edge of plating or below it at a distance not more than 50 mm from the extended side plating of the superstructure. The plating is also to be additionally stiffened.

In general, openings are not to be located in the extended superstructure plating. The superstructure plating is not to be connected with the bulwark.

10.2.1.4 Openings in the sides of long deckhouses are to have well rounded corners.

Horizontal stiffeners are to be fitted at the upper and lower edge of window openings.

Door openings in the sides are to be stiffened along the edges. Plate panels below and above the doors are to be continuous and their thickness is to be increased.

10.2.1.5 Cross-sectional area of welds connecting deckhouse corners with deck plating is to be increased with respect to that normally required.

Corners of long deckhouses situated on the strength deck shall be connected to the end bulkheads (forward or aft) applying radius of curvature calculated by the formula:

$$R = 0.02\, l_p, \quad [\text{m}] \qquad (10.2.1.5)$$

l_p – length of deckhouse, [m].

The assumed value of R need not be greater than 1.4 m.

10.2.1.6 If sides of long deckhouses are not in line with longitudinal bulkheads or girders, but are supported by deck beams only, then deck girders are to be fitted in line with deckhouse sides. The girders are to extend three frame spaces forward and aft beyond the deckhouse ends. The depth of the girders is not to be less than that of the deck beams plus 100 mm, and at its ends may be equal to the depth of the deck beams.

10.2.1.7 Deck beams under fore and aft ends of deckhouses are not to be scalloped in way of deckhouse corners.

10.2.2 Additional Requirements

10.2.2.1 Companionways situated on exposed decks are to be efficiently stiffened in accordance with the requirements for deckhouses.

10.2.2.2 Adequate strengthening of sides and decks in deckhouses is to be provided in those places where life boats, boat davits, masts, hoisting winches are situated, as well as in other places where excessive local loads are likely to occur.

10.2.2.3 The flexible seatings for superstructures and deckhouses will be specially considered by PRS in each particular case.

10.2.2.4 In ships where the strength deck is formed by superstructure deck with length less than the total ship's length, or where in superstructure walls openings of significant dimensions or a considerable number of smaller openings are applied, when assessing the strength, superstructure incomplete effectiveness of bending moments and shear stresses transfer is to be taken into account.

10.2.2.5 In such case MES model calculations for the all ship's hull – according to 14.6 – will be required.

10.2.3 Sponsons

The sponsons' girder system should fit to the hull girders configuration.

The end parts of sponsons should be smoothly chamfered – at the length not less than 5 frame spaces.

10.3 Scantlings of Structural Members

10.3.1 Wall Plating

10.3.1.1 The plating thickness of exposed end bulkheads of superstructures and deckhouses, as well as of exposed sides of deckhouses resulting from lateral external pressure is not to be less than that determined from the formula:

$$t = 18 k_a s \sqrt{\frac{p}{\sigma}}, \quad \text{[mm]} \qquad (10.3.1.1)$$

k_a – to be determined as in 13.4.2.1;
p – see 10.4;
σ = 160 k, [MPa].

10.3.1.2 The final plate thickness of superstructures and deckhouses walls is not to be less than:

– for the lowest tier:

$$t = 5 + 0.01 L_0, \quad \text{[mm]} \qquad (10.3.1.2\text{-}1)$$

but need not be greater than 8 mm;

– for the other tiers:

$$t = 4 + 0.01 L_0, \quad \text{[mm]} \qquad (10.3.1.2\text{-}2)$$

but not less than 5 mm; t need not be greater than 7 mm.

10.3.1.3 The thickness of deckhouse plates need not exceed that required for the side plating in a superstructure in the same area.

10.3.1.4 The thickness of sponsons plating is to be determined as for decks and sides.

For stiffened sponsons – outside the middle part of the ship – slamming pressure, determined according to 7.4.5 is to be considered, and plating thickness calculated according to 7.4.2.

10.3.2 Walls Stiffeners

10.3.2.1 The section modulus of stiffeners of end bulkheads of superstructures and deckhouses and in deckhouse sides is not to be less than determined from the formula:

$$W = \frac{100\, l^2 s\, p}{\sigma}, \quad [\text{cm}^3] \tag{10.3.2.1}$$

p – see 10.4;
σ = 160 k, [MPa] – for longitudinal and vertical stiffeners, in general,
σ = 90 k, [MPa] – for longitudinals at strength deck in long deckhouses amidships; the value of σ may be increased linearly to 160 k at the first tier deck and at the end parts of the ship,
l, s – see 10.1.3.

10.3.2.2 The scantlings of side stiffeners in superstructures need not be greater than those required for 'tween deck frames with the equivalent connection of stiffener ends.

10.3.2.3 Stiffeners of fore end bulkheads are to be connected to deck at both ends with a connection area not less than determined from the formula:

$$A_p = \frac{0.07\, l\, s\, p}{k}, \quad [\text{cm}^2] \tag{10.3.2.3}$$

p – see 10.4,
l, s – see 10.1.3.

Stiffeners of side walls and aft end bulkheads in the lowest tier of erections are to have end connections as brackets or are to be welded to the decks.

10.3.2.4 The section modulus of sponsons' stiffeners is to be additionally checked for compliance with requirements of 7.4.3, taking into account slamming pressure determined according to 7.4.5.

10.3.3 Casings

10.3.3.1 The plating thickness in protected casings is not to be less than determined from the formula:
– in way of cargo holds:

$$t = 8.5\, s \quad \text{but} \quad t \geq 6, \quad [\text{mm}] \tag{10.3.3.1-1}$$

– in way of accommodations:

$$t = 6.5\, s \quad \text{but} \quad t \geq 5, \quad [\text{mm}] \tag{10.3.3.1-2}$$

10.3.3.2 The section modulus of stiffeners is not to be less than determined from the formula:

$$W = 3\, l^2 s, \quad [\text{cm}^3] \tag{10.3.3.2}$$

l – length of stiffeners, but $l \geq 2.5$ [m],
s – stiffeners spacing, [m].

10.3.3.3 Casings supporting one or more decks are to be adequately strengthened and the scantlings of stiffeners are to comply with the requirements of 13.7.3.

10.3.4 Aluminium Alloy Superstructures

10.3.4.1 The strength of aluminium alloy superstructures and deckhouses is to be equivalent to that required for steel structures. Connections of steel and aluminium alloy structures are to be made in compliance with the requirements of 4.4.

10.3.4.2 Engine and boiler room casings, as well as decks with accommodation and duty spaces located above the machinery space and functional ships spaces (e.g. storerooms) are to be made of steel.

10.4 Walls Design Loads

10.4.1 The design sea pressure p acting on the exposed end bulkheads of super-structures and deckhouses, as well as side walls of deckhouses is to be determined in compliance with the requirements of Chapter 17.

10.4.2 The design pressure p assumed for calculation of fore end bulkheads of the lowest tier of superstructures and deckhouses is to be not less than that deter-mined from the formula:

$$p = 12.5 + 0.05L_0 \,, \quad \text{[kPa]} \qquad (10.4.2\text{-}1)$$

The design pressure p assumed for the remaining tiers is to be not less than that determined from the formula:

$$p = 6.25 + 0.025L_0 \,, \quad \text{[kPa]} \qquad (10.4.2\text{-}2)$$

10.4.3 The design pressure for the exposed side walls of deckhouses is not to be less than that determined from formula 10.4.2-2.

10.4.4 The design pressure for the exposed aft end bulkheads of superstructures and deckhouses is not to be less than that determined from formula 10.4.2-2.

10.5 Bulwarks

10.5.1 General Requirements

10.5.1.1 The requirements concerning location and height of bulwarks are given in *Part III – Hull Equipment*.

10.5.1.2 The design of the bulwark structure is to preclude it from taking part in the general bending of the hull. The bulwarks which are extension of the side shall be separately considered by PRS.

10.5.1.3 Where, in some place, the bulwark is welded to the sheer strake, the smooth transition with a radius of at least 100 mm between the bulwark plating and the sheer strake is to be maintained.

10.5.1.4 Sufficient provision is to be made for freeing the decks from water, particularly in areas where bulwarks and superstructures form wells.

10.5.2 Bulwark Thickness

10.5.2.1 If the bulwarks are of Rule height, their thickness is not to be less than:

$$t = 0.065L_0 + 1.75, \quad [\text{mm}] \quad \text{for} \quad L_0 \le 60 \text{ m} \qquad (10.5.2.1\text{-}1)$$

$$t = 0.025L_0 + 4.00, \quad [\text{mm}] \quad \text{for} \quad L_0 > 60 \text{ m} \qquad (10.5.2.1\text{-}2)$$

The thickness of bulwark plate is not to be less than 3 mm and need not be greater than 8 mm and not greater than that required for the side plating in superstructures.

10.5.2.2 Where the height of a bulwark is 1.8 m and more, the thickness of bulwark plates is to comply with the requirements of 10.3 for side plating in superstructures. The thickness of bulwark plates may be found by linear interpolation when the height of a bulwark is greater than the Rule value and less than 1.8 m.

10.5.2.3 The thickness of bulwark plates in the first tier of superstructures in way of $x \le 0.25L_0$, as well as of superstructures and deckhouses of the second tier and the tiers above may be decreased by 1 mm.

10.5.3 Stiffenings and Bulwark Rails

10.5.3.1 The upper edge of the bulwark is to end with a rail made of adequate firm section, the thickness of which is at least 1 mm greater than that of the bulwark plating.

10.5.3.2 The lower edge of the bulwark in way of a gap between the bulwark and the sheer strake is to be strengthened by a longitudinal stiffener or a flange.

10.5.4 Arrangement of Stays

10.5.4.1 The bulwark is to be supported by stays spaced not more than 1.8 m. In the fore part of the ship for $x > 0.43\ L_0$, spacing between stays are to be decreased to 1.2 m. Where the flare is large and in ships intended for the carriage of timber on deck, spacings between stays will be specially considered by the PRS.

10.5.4.2 The stays are to be in line with beams, brackets or additional deck stiffeners.

10.5.5 Scantlings and Structure of Stays

10.5.5.1 Where the bulwark height is 1 m, the width of the lower end of a stay, measured along the connection with the deck, is not to be less than:

$$b = \left(0.65L_0 + 190\right)\sqrt{s}, \quad [\text{mm}] \qquad (10.5.5.1)$$

but need not exceed 360 mm.

s – spacing between stays, [m]; in the fore part of the ship, s = 1.8 m is to be taken for calculations, irrespective of a real spacing between stays.

Outside the bow region, where bulwark is welded to the sheer strake, *b* may be reduced by 20%. Where the height of the bulwark exceeds 1 m, the width *b* is to be increased in proportion to the bulwark height.

10.5.5.2 The thickness of stays is to be 1 mm greater than that of the bulwark plating.

10.5.5.3 Stays are to have flanges or flat bars welded to free edges. The width of a flat bar is not to be less than 60 mm, but it is not to exceed 90 mm. Flanges (flat bars) and stiffeners strengthening the lower edge of the bulwark are not to be welded to the deck.

10.5.5.4 The dimensions of lightening holes in stays are not to exceed half the stay width in any cross-section.

10.5.5.5 The thickness of stays in way of bulwark cut to form a passage is to exceed the bulwark thickness by 25%. Additional strengthening of bulwark may be required in way of mooring pipes, fairleads and eyeplates for rigging.

10.5.5.6 Stays are to be welded to rail, bulwark and deck. The stay is to be welded to the deck with double continuous weld. Adequate openings are to be provided for freeing the deck of water.

11 STEM, RUDDER HORNS, FIXED NOZZLES AND SHAFT BRACKETS (STRUTS)

11.1 General

11.1.1 Application

The requirements of the present Chapter are applicable to the construction, shape and scantlings of stems, fixed nozzles, rudder horns and shaft brackets.

11.1.2 General Requirements

11.1.2.1 Steel castings of stems and sternframes are to be of simple shape with adequately long radii of casting.

11.1.2.2 The welded structure (steel casting) of the stem is to be strengthened by transverse brackets (cast webs).

11.1.2.3 The thickness of plates (the thickness of casting edges) in way of connection with the hull structure is to be reduced to the thickness of members to which the stem will be welded.

11.2 Stem

11.2.1 Structure

11.2.1.1 The stem steel plates are to be strengthened by transversal brackets fitted not greater than 1 m apart below the design waterline and not greater than 1.5 m apart above the design waterline. Longitudinal strengthening for the connection with the bottom centre girder in the stem structure is to be provided.

11.2.1.2 Where the distance between brackets, required in 11.2.1.1, is reduced by 0.5 m, the thickness of stem plates may be reduced by 20% in relation to requirements given below. The plate thickness, however, is not to be less than that of the adjoining shell plating. The brackets are to extend beyond the joints of the stem with the shell plating. They are to be welded to the nearest frames and their thickness is to be equal to that of the shell plating.

11.2.1.3 Where a radius of curvature of the stem exceeds 200 mm at the level of the design waterline, a centreline web with face plates is to be fitted from the keel to the level of 0.15 T above the designwaterline along free edge. The thickness of the web and the face plate is not to be less than that of the transverse brackets.

11.2.1.4 Where a radius of curvature of the bow is large, the stem design will be specially considered by the PRS.

11.2.2 Scantlings

11.2.2.1 The dimensions of bar stem cross-section from the keel to the design waterline are not to be less than those determined by the following formulae:

– length: $l = 1.2L_0 + 95$, [mm] for $L_0 < 120$ m (11.2.2.1-1)

$l = 0.75L_0 + 150$, [mm] for $L_0 \geq 120$ m (11.2.2.1-2)

– breadth: $b = 0.4L_0 + 15$, [mm] (11.2.2.1-3)

but not more than 100 mm.

Above the design waterline, the cross-section area of the stem may be gradually tapered to 70% of the area obtained from the scantlings given above.

11.2.2.2 Fabricated stems are to be made of steel plates, the thickness of which is to be determined from the formula:

$$t = 0.105L_0 + 4, \quad \text{[mm]} \qquad (11.2.2.2)$$

but not less than 7 mm.

At $T / L_0 \geq 0.065$, the thickness of the welded stem obtained by the above formula is to be multiplied by the factor $(0.35 + 10\, T / L_0)$.

Moreover, the adopted thickness of plates is in no case to be less than that of the plate keel in way of attachment to the stem foot. Above the design waterline, the plate thickness may be gradually tapered to the thickness of the shell plating at the ship ends.

11.2.2.3 The length of the cross-section of the fabricated stem is recommended to be not less than twice that of the bar stem required in 11.2.2.1.

11.2.3 Bow Bulb Structure

11.2.3.1 The bulb structure is to be strengthened by the stiffened horizontal platforms at spacing not exceeding 2 m.

11.2.3.2 Where the length of the bulb, measured from the forward perpendicular, exceeds 0.03 L_0, the non-tight bulkhead is to be fitted in the centreline. Where the bulb length is less than that given above, a deep frame may be used instead of a bulkhead.

11.2.3.3 Irrespective of compliance with the requirements of Chapters 6 and 7 for the thickness of the bottom and side plating, the thickness of bulb plating is not to be less than that calculated from the formula:

$$t = 0.08L_0 + 6, \quad \text{[mm]} \qquad (11.2.3.3)$$

11.2.3.4 The form of the fore part of the hull is to provide for free anchorage at a bulb at a heel of 5° to the opposite side. Additional strengthening is to be fitted in way of the possible anchor blows.

11.3 Rudder Horn

11.3.1 The rudder horn is to be effectively attached to the adjacent hull structure.

11.3.2 The section modulus of the horizontal section of the rudder horn, calculated for the longitudinal neutral axis, is to be not less than that calculated from the formula:

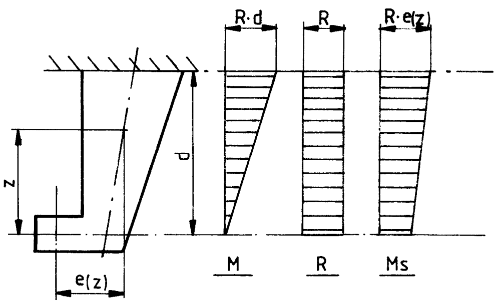
$$W = \frac{M}{67k}, \quad [\text{cm}^3] \qquad (11.3.2\text{-}1)$$

$$M = Rz, \quad [\text{Nm}] \qquad (11.3.2\text{-}2)$$

$$M_{\max} = Rd, \quad [\text{Nm}] \qquad (11.3.2\text{-}3)$$

$$R = \frac{Fb}{l_2}, \quad [\text{N}] \qquad (11.3.2\text{-}4)$$

R – assumed reaction force acting in the bearing located in the horizontal arm of the rudder horn, [N];
F – the assumed force acting on the rudder blade, [N], defined in *Part III – Hull Equipment*;
z, *d* – see Fig. 11.3.2-1;
b, l_2 – see Fig. 11.3.2-2.



M – bending moment, T_s – sheer force, M_s – torsional moment

Fig. 11.3.2-1 Rudder horn

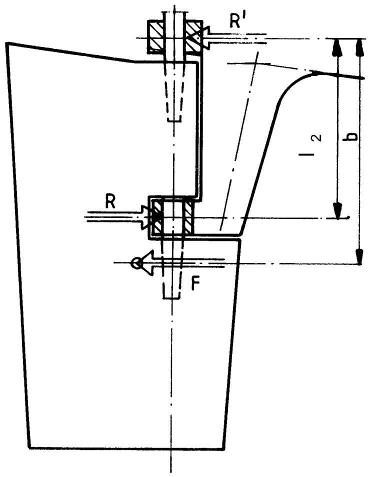


Fig. 11.3.2-2 Forces in semi-spade rudder

11.3.3 In no place of the rudder horn the shear stress is to be greater than:

$$\tau = 48\,k, \quad [\text{MPa}]$$

11.3.4 In no place of the rudder horn the equivalent stress is to be greater than 120 k, [MPa].

11.3.5 The stresses are to be be calculated from the formulae:

$$\sigma_e = \sqrt{\sigma_n^2 + 3\left(\tau_n^2 + \tau_s^2\right)}, \quad [\text{MPa}] \qquad (11.3.5\text{-}1)$$

$$\sigma_n = \frac{M}{W}, \quad [\text{MPa}] \qquad (11.3.5\text{-}2)$$

$$\tau_n = \frac{R}{100 A_h}, \quad [\text{MPa}] \qquad (11.3.5\text{-}3)$$

$$\tau_s = \frac{10 M_s}{2 A_s t_h}, \quad [\text{MPa}] \qquad (11.3.5\text{-}4)$$

$$M_s = R\,e(z), \quad [\text{Nm}] \qquad (11.3.5\text{-}5)$$

A_h – effective cross-section area of the rudder horn for shear in y-direction, [cm^2];
A_s – horizontal cross-section area enclosed by the rudder horn, [cm^2];
t_h – thickness of rudder horn plating, [mm];
σ_n – normal stress, [MPa];
σ_e – equivalent stress, [MPa];
τ_s – torsional stress, [MPa];
τ_n – shear stress, [MPa];
M_s – torsional moment, [Nm];
e(z) – see Fig. 11.3.2-1.

When calculating the real section modulus of the rudder horn, the total horizontal cross-section area of the rudder horn elements may be taken into account.

11.3.6 Where the connection between the rudder horn and the hull structure is designed as a smooth transition into the hull plating (transition zone), then for the horizontal section, situated 0.7 r above the point where the smooth transition starts (see Fig. 11.3.6), the section modulus, as given in 11.3.2, is to satisfy the following condition:

$$W_p = \frac{\sum_{i=1}^{n} b_i^3 t_i}{6000 b_m} \geq 0.45 W \qquad (11.3.6)$$

n – number of horn transverse webs;
b_i – effective breadth of i web (including thicknesses of the both effective platings within the transition zone), [mm];
b_m – the largest b_i, [mm];
t_i – thickness of i web, [mm];
r – transition zone curvature radius;
W – see 11.3.2.

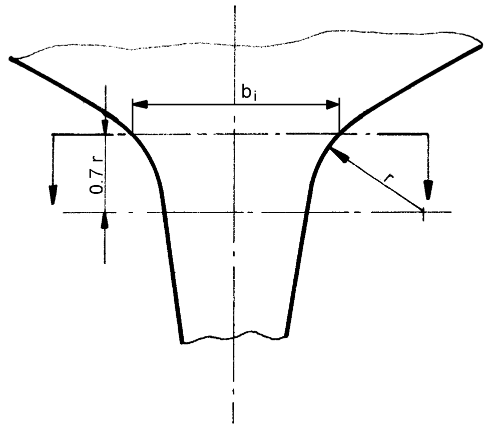


Fig. 11.3.6 Transition zone between rudder horn and hull plating

11.3.7 The thickness of rudder horn plating is not to be less than:

$$t = \frac{11 F e}{n k A_s 100}, \quad [\text{mm}] \qquad (11.3.7\text{-}1)$$

$$n = 0.02 \sqrt{4000 - 1500 \left(\frac{W}{W_0} \right)^2} \qquad (11.3.7\text{-}2)$$

F – see 11.3.2;
e – horizontal projected distance from the centreline of the horn pintle bearing to the centroid of the area A_s, [m];
A_s – see 11.3.5;

W_0 – section modulus of the rudder horn at the cross-section where the transition zone between the rudder horn and shell plating begins, see Fig. 11.3.6, [cm^3];
W – the rudder horn section modulus in the same section, determined according to 11.3.2.

11.3.8 The lower end of the rudder horn is to be covered by a horizontal plate, the thickness of which is not less than that of the side plating of the rudder horn.

11.3.9 For a curved transition between the horn plating and shell plating, the thickness of the transition zone plate is not to be less than:

$$t_c = \frac{0.15(s-40)}{r}\frac{W}{W_0}, \quad \text{[mm]} \tag{11.3.9}$$

s – spacing between vertical transverse webs, [mm];
r – transition zone curvature radius, [mm];
W_0, W – as in 11.3.7.

11.3.10 The vertical parts of the rudder horn participating in the strength against transverse shear are to have a total area in horizontal cross-section not less than that calculated from the formula:

$$A_w = c\frac{0.3F}{k}\cdot 10^{-3}, \quad \text{[cm}^2\text{]} \tag{11.3.10}$$

$c = 1 + \dfrac{(A + A_0)A_0}{A^2}$ – at the upper end of the rudder horn;
c = 1 – at the lower end of the rudder horn;
A – area (lateral projection) of the rudder blade, [m^2];
A_0 – area (lateral projection) of the rudder horn, [m^2];
F – as in 11.3.2.

11.3.11 The thickness of the vertical transverse webs in the transition zone is not to be less than:

$$t_r = \frac{b\,t_c}{r}, \quad \text{[mm]} \tag{11.3.11}$$

b – breadth of the curved plate in the transition zone supported by the web in question, [mm];
t_c – thickness of the curved plate in the transition zone supported by the web in question, [mm];
r – as given in 11.3.9.

11.3.12 Direct stress analysis of the rudder horn, if applied, is to be based on a finite element method.

The maximum allowable stresses are:
- normal stresses: $\sigma = 120k$, [MPa];
- shear stresses: $\tau = 50k$, [MPa];
- equivalent stresses: $\sigma_e = 180k$, [MPa].

For a curved transition to the hull structure, the maximum allowable normal and equivalent stresses, given in 11.3.2.1, may be increased to:
$\sigma_n = 120\ k$, [MPa];
$\sigma_e = 180\ k$, [MPa].

In webs, the normal stresses are not to exceed the value of $\sigma_n = 130\ k$, [MPa].

11.3.13 The alternative design of the rudder horn connected to the hull structure without the transition zone is shown in Fig. 11.3.13.

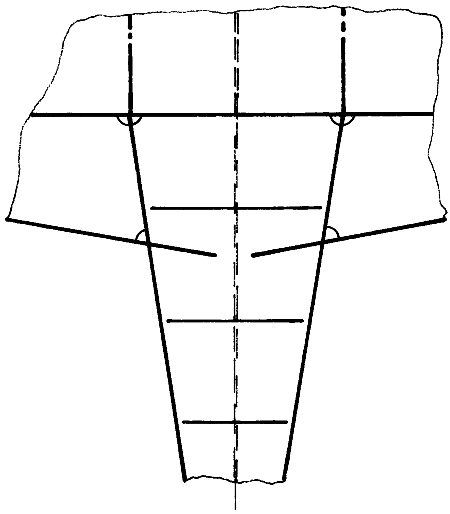


Fig. 11.3.13 Alternative solution without transition zone

11.4 Clearances between the Propeller and the Hull

11.4.1 The afterbody is to be so shaped as to ensure a proper flow of water to the propeller and so as to ensure, as far as possible, uniform wake current field velocity.

11.4.2 For moderately cavitating propellers, the following minimum clearances are to be taken (see Fig. 11.4.2):

– single-screw ships:
  $a \geq 0.2\ R_s$, [m],
  $b \geq (0.7 - 0.04\ Z_s)$, [m],
  $c \geq (0.48 - 0.02\ Z_s)\ R_s$, [m],
  $e \geq 0.07\ R_s$, [m];

– twin-screw ships:
  $c \geq (0.6 - 0.02\ Z_s)\ R_s$, [m];
  R_s – propeller radius, [m],
  Z_s – number of propeller blades.

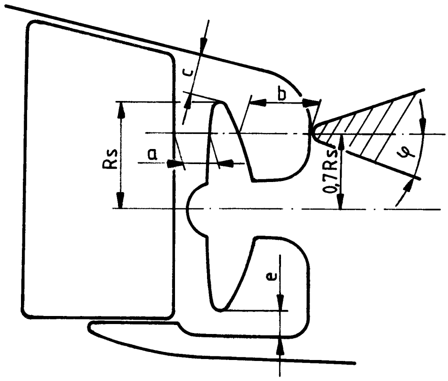


Fig. 11.4.2 Propeller clearance

11.4.3 The apex of the waterlines in front of the propeller is to have the least possible radius *r* and an angle φ . Plane or approximately plane parts above the propeller tip are to be avoided.

11.5 Fixed Nozzles

11.5.1 Application

The requirements of the present sub-chapter apply to fixed nozzles of the inner diameter not exceeding 4 m, made of normal strength structural steel. The application of other materials will be specially considered by the PRS. Nozzles with the inner diameter greater than 4 m will be specially considered by the PRS based on vibration analysis.

11.5.2 Plating

11.5.2.1 The thickness of the nozzle shell in the propeller zone (see Fig. 11.5.2.1) is to be determined from the formula:

– for steel with increased corrosion resistance:

$$t = 3.5 + 2.5 n s \sqrt{p}, \quad \text{[mm]} \qquad (11.5.2.1\text{-}1)$$

but not less than 10 mm;

– all other cases:

$$t = 7 + 2.5 n s \sqrt{p}, \quad \text{[mm]} \qquad (11.5.2.1\text{-}2)$$

but not less than 10 mm;

s – distance between ring webs, [m]; $s \geq 0.35$ m is to be taken for calculations;

n – nozzle curvature factor,

$$n = 1 - 0.14\frac{s}{l}\sqrt{d} \qquad (11.5.2.1\text{-}3)$$

l – distance between longitudinal webs of nozzle, measured on the outer plating of the nozzle, [m];

d – propeller diameter, [m];

p – pressure on the nozzle plating,

$$p = 0.25\frac{N}{A}\left(1 - 0.001\frac{N}{A}\right), \quad \text{[kPa]} \qquad (11.5.2.1\text{-}4)$$

N – output delivered to the propeller, [kW];

$$A = \frac{\pi d^2}{4}, \quad [\text{m}^2] \qquad (11.5.2.1\text{-}5)$$

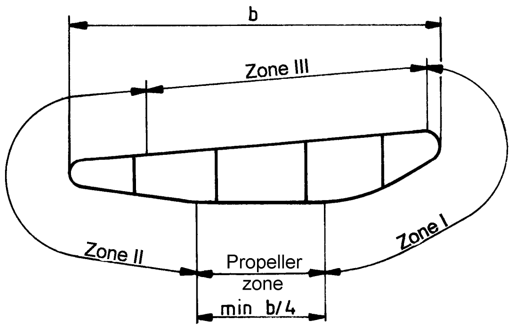


Fig. 11.5.2.1 Longitudinal section through nozzle ring

11.5.2.2 The length of the propeller zone is not to be less than 0.25 *b* (*b* – nozzle length, see Fig. 11.5.2.1).

11.5.2.3 The plating thickness in zones I and II (see Fig. 11.5.2.1) is to be determined from formula 11.5.2.1-2, assuming 0.5 *p* determined from formula 11.5.2.1-4. The plating thickness within these areas is not to be less than 8 mm.

11.5.2.4 The plating thickness in zone III (see Fig. 11.5.2.1) is to be determined from formula 11.5.2.1-2, assuming 0.35 *p* determined from formula 11.5.2.1-4.

11.5.2.5 The outer plating in zone II of the nozzle is to cover at least one ring web (see Fig. 11.5.2.1).

11.5.2.6 The thickness of ring webs, as well as longitudinal webs is not to be less than 0.6 *t* (*t* – calculated according to 11.5.2.1), but not less than 8 mm.

11.5.2.7 In ships with ice strengthening, the nozzle plating thickness is not to be less than that required for the hull plating in the considered part of ship.

11.5.3 Section Modulus of the Longitudinal Section of Nozzle

The section modulus of the longitudinal section of nozzle ring calculated for the neutral axis parallel to the ship centreline is not to be less than the values determined from the formulae:

$$W = 0.7bD^2v^2, \quad [\text{cm}^3] \tag{11.5.3-1}$$

$$W = 6DP, \quad [\text{cm}^3] \tag{11.5.3-2}$$

b – nozzle ring length (see Fig. 11.5.2.1), [m];
D – diameter of the nozzle measured to the middle of its thickness, [m];
v – ship speed, [knots]; in ships with ice strengthenings the speed, taken for calculations, is not to be less than 14, 15, 16 or 17 knots for Ice Class **L3**, **L2**, **L1** or **L1A**, respectively;
P – water pressure on the nozzle surface,

$$P = 20\frac{D^2}{T^2}bL_0\Theta_A, \quad [\text{kN}] \tag{11.5.3-3}$$

Θ_A – pitch amplitude, in radians, according to 17.5.3.2;
T – pitch period, [s], determined from the formula:

$$T = 1.8\sqrt{\frac{L_0}{g}}, \quad [\text{s}]$$

11.5.4 Welding

11.5.4.1 The ring webs are to be welded to the inner plating of the nozzle with double continuous fillet welding.

11.5.4.2 The ring webs are to be, as far as possible, welded continuously to the outer plating of the nozzle. All welds of webs to the outer plating may be slot welds if the web spacing does not exceed 350 mm. Otherwise, at least two ring webs are to be welded continuously to the outer shell.

11.5.5 Supporting

11.5.5.1 The nozzle is to be supported by at least two supports. The web plates and plating of the supporting structure are to be in line with web plates in the nozzle.

11.5.5.2 The resultant horizontal force acting on the nozzle side may be determined from the formula:

$$P = 0.2bDv, \quad [\text{kN}] \tag{11.5.5.2}$$

b, D, v – see 11.5.3.

Vertical water pressure acting on the nozzle external surface due to the ship's pitch may be determined according to formula 11.5.3-3.

11.5.5.3 In no place of the nozzle supporting structure the equivalent stress is to exceed 100 MPa.

11.6 Shaft Brackets

11.6.1 General Reuiqrements

Requirements of sub-chapter 11.6 apply to structures supporting shafts outside the hull. These structures may take the form of sterntube (see 11.6.2) or struts (see 11.6.3 and 11.6.4). These design solutions are typical for twin propellered ships.

11.6.2 Sterntube

11.6.2.1 Plating of the sterntube shall pass smoothly into the hull plating.

In its aft part, the sterntube shall be stiffened by the transverse partitions located in frames planes – at each frame.

Partitions should be stiffened and connected to the hull floors or with relevant hull girder system.

In the fore part of the sterntube, the partitions shall be applied at intervals of not more than two frame spacings.

11.6.2.2 At its end the sterntube shall be provided with a hub in a form of casting or prefabricated structure, supporting the shaft bearing. The construction of the hub shall be sufficiently strong to carry the shaft reaction to the ship's hull structure.

In the case of ships with the high power propulsion the direct FEM calculations of the sterntube strength and vibration analysis may be required.

11.6.3 The Design and Strength of the Struts (Shaft Brackets)

11.6.3.1 The feet of the struts made in form of castings shall be of shape ensuring smooth passing to the hull shape. The arm of the struts shall be strengthened with ribs.

11.6.3.2 Prefabricated struts shall be so designed that the concentration of stresses in the notches area is minimized. They shall be connected to the hull floors or to the special hull girders system.

The arm shall be welded to the hubs supporting shaft bearings with full penetration welds.

11.6.3.3 Scantling of the struts shall ensure compliance with requirements given in 11.6.3.7 (single-arm struts) or in 11.6.3.8 and 11.6.3.9 (double-arm struts).

In the case of ships with the high power propulsion the direct FEM calculations of the struts' strength and vibration analysis may be required.

11.6.3.4 The propeller shaft uncovered by the sterntube shall be supported in the immediate vicinity of the propeller (propulsor) by the two-arm strut.

In the case of small ships, application of a single-arm strut may be accepted.

11.6.3.5 The struts' arms shall continuously pass through the hull shell plating and be connected to the floors with increased thickness, or to the special girders.

The hull side shell in region of the arms shall be of increased thickness and welded to the arms with full penetration welds.

11.6.3.6 Sterntubes supported by the struts, made of the materials with the same as propeller shaft strength limit R_m , shall have length l_p and thickness t_p meeting the conditions:

$$l_p \geq 4d_w \qquad (11.6.3.6\text{-}1)$$

$$t_p \geq 0{,}25d_w \qquad (11.6.3.6\text{-}2)$$

where:

d_w – propeller shaft diameter required by *Part VII – Machinery, Boilers and Pressure Vessels*, [mm].

In case of sterntube made of materials with other values of R_m, the required values of l_p and t_p shall be agreed with PRS in each case.

11.6.3.7 Section modulus of the single-arm strut located in a immediate vicinity of the propellers shall have at its base (by the hull shell plating) the value not less than:

$$W_r = \frac{l_r \cdot d_w^2}{115R_m}, \ [\text{cm}^3] \qquad (11.6.3.7)$$

where:

l_r – length of the arm measured from the propeller shaft axis to the surface of the hull shell plating, [mm];

d_w – as in 11.6.3.6;

R_m – the arm material strength limit, [MPa].

The strut's cross section dimensions in place of its connection to the hub shall not be less than 60% of the value obtained from the formula 11.6.3.7.

11.6.3.8 The angle α between arms of double-arm struts (Fig.11.6.3.8) shall not be less than 50°.

In case where α < 50°, strut strength calculations, justifying such design solution, shall be presented to PRS.

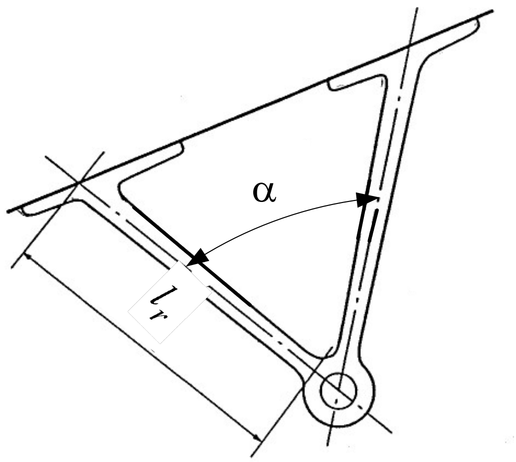


Fig. 11.6.3.8 Double-arm strut

11.6.3.9 Section modulus of the double-arm strut located in the immediate vicinity of the propellers shall have at its base the value not less than:

$$W_r = 0.45c^3, \ [\text{cm}^3] \qquad (11.6.3.9\text{-}1)$$

where:

$$c = d_w \sqrt{\frac{1}{5 \cdot R_m}\left(1 + \sqrt{1 + \frac{R_m}{35000}\left(\frac{l_r}{d_w}\right)^2}\right)}$$

d_w – as in 11.6.3.6;
R_m – the strut material strength limit, [MPa].
l_r – length of the shorter arm, [mm] (see Fig. 11.6.3.8).

11.6.4 Intermediate Struts (Shaft Brackets)

The hubs of the struts, other than located in the immediate vicinity of the propeller, shall have dimensions not less than required in 11.6.3.6.

The dimensions of the struts' arms less than required in 11.6.3.7 and 11.6.3.9, shall be, in each case, subject to PRS separate consideration.

11.6.5 Shaft Brackets' (Struts) Bolted Connection to the Hull

11.6.5.1 The side shell thickness in the area of shaft brackets' feet fixing shall be increased, as follows:
– not less than 50% in case of application of double-arm struts;
– not less than 100% in case of application of single-arm struts.

11.6.5.2 The struts' feet shall have rounded corners. Surfaces faying the hull shall be adequately smooth. Thickness of the foot in the place of fixing bolts shall not be less that thickness of the hubs required in 11.6.3.6.

11.6.5.3 Feet of intermediate struts may be fixed directly to the hull shell, and – for ensuring axial alignment – by application of adjusting washers, made by recognized manufacturers.

Application of plastic washers shall be separately considered by PRS.

11.6.5.4 Feet of struts located in the immediate vicinity of propellers shall be fixed on steel washers with thickness not less than 15 % of the foot's thickness, but not less than 3 mm.

Fixing bolts shall, in such case, be permanently fixed to the feet.

11.6.5.5 The nuts of bolts fixing feet to the hull shall be secured against loosening.

11.6.5.6 Diameter of the bolts fixing strut's feet to the hull shall not be less than:

$$d = 60\sqrt{\frac{W_r}{n \cdot u}} \cdot \sqrt{\frac{R_{ew}}{R_{es}}}\ , \ \text{[mm]} \qquad (11.6.4.6)$$

where:

W_r – required section modulus of the strut's arm, determined in accordance with 11.6.3.7 or 11.6.3.9;

n – number of bolts in a row;

u – distance between bolts' rows, [mm];

R_{ew} – yield point of the strut's material, [MPa];

R_{es} – Yield point of the bolts' material, [MPa].

Actual diameter of the bolts shall not be less than thickness of the foot required in 11.6.4.2.

11.7 Sternframe

11.7.1 Structure

11.7.1.1 Sternframe shall be effectively attached to the adjacent hull structure. For this purpose, it shall be strengthened by transverse brackets (webs).

11.7.1.2 Greater propeller posts of the cast sternframes may be made of pieces. Adequate strength of connections of each sternframe piece shall be provided. Welded structure of propeller posts, formed by the adequate steel sections and plates welded to them, may be applied.

11.7.2 Scantlings

11.7.2.1 Where the scantlings of sternframe are based on the stress analysis, the stress values shall not be greater than:

– normal stress: $\sigma_n = 80k$ [MPa],

– shear stress: $\tau = 50k$ [MPa],

– equivalent stress: $\sigma_e = 125k$ [MPa].

11.7.2.2 Thickness of the propeller boss shall not be less than that determined in accordance with the following formula:

$$t = 5\sqrt{d_p - 60} \quad \text{[mm]} \qquad (11.7.2.2)$$

d_p d_{srp} – Rule diameter of the propeller shaft, [mm], calculated according to requirements of *Part VI – Machinery Installations and Refrigerating Plants*.

11.7.2.3 The dimensions of the welded propeller post shall not be less than those determined in accordance with the following formulae (see Fig. 11.7.2.3):

$$l = 53\sqrt{L_0} \quad \text{[mm]} \qquad (11.7.2.3\text{-}1)$$

$$b = 37\sqrt{L_0} \quad \text{[mm]} \qquad (11.7.2.3\text{-}2)$$

$$t = 2.4\sqrt{\frac{L_0}{k}} \quad \text{[mm]} \qquad (11.7.2.3\text{-}3)$$

When the assumed cross-section is different from that shown in Fig. 11.7.2.3, the section modulus calculated for the longitudinal neutral axis shall not be less than that determined in accordance with the following formula:

$$W_s = \frac{1.35 L_0 \sqrt{L_0}}{k} \quad \text{[cm}^3\text{]} \qquad (11.7.2.3\text{-}4)$$

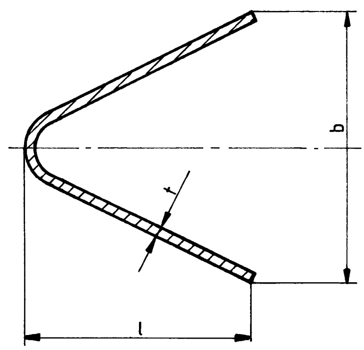


Fig. 11.7.2.3 Welded sternframe propeller post

11.7.2.4 Dimensions of the cast propeller post shall not be less than those determined in accordance with the following formulae (see Fig. 11.7.2.4):

$$l = 40\sqrt{L_0} \quad \text{[mm]} \qquad (11.7.2.4\text{-}1)$$

$$b = 30\sqrt{L_0} \quad \text{[mm]} \qquad (11.7.2.4\text{-}2)$$

$$t_1 = 3\sqrt{\frac{L_0}{k}} \quad \text{[mm]} \qquad (11.7.2.4\text{-}3)$$

$$t_2 = 3.7\sqrt{\frac{L_0}{k}} \quad \text{[mm]} \qquad (11.7.2.4\text{-}4)$$

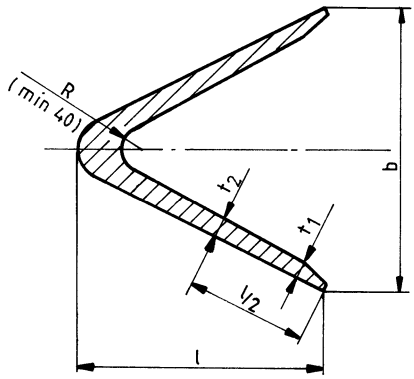


Fig. 11.7.2.4 Cast sternframe propeller post

When the assumed cross-section is different from that shown in Fig. 11.7.2.4, the section modulus calculated for the longitudinal neutral axis shall not be less than that determined in accordance with the following formula:

$$W_s = \frac{1.3 L_0 \sqrt{L_0}}{k} \quad [\text{cm}^3] \qquad (11.7.2.4\text{-}5)$$

When determining the section modulus of the propeller post, the adjacent plating of the width up to $53\sqrt{L_0}$ [mm], measured from the aft edge of the propeller post, may be taken into account. This applies also to the welded propeller post.

12 SEATINGS

12.1 General

12.1.1 Application

The requirements of the present Chapter are applicable to the construction of seatings for the main engines, boilers, as well as for deck, processing, cargo handling, auxiliary and other machinery.

12.1.2 General Requirements

12.1.2.1 The main engine seatings and other machinery equipment are to have a strong and rigid structure attached to the strength members of the bottom, sides and decks so as to ensure the transmission of longitudinal and transverse static and dynamic loads from the considered machinery to the hull structure.

12.1.2.2 Access is to be provided to ensure the strength members under the seating to be inspected and measures are to be taken to prevent water from accumulating under the seating. Upon the PRS' agreement, a tight structure of the seating may be applied, the inner space of the seating being filled with chemically inert material with good adhesion properties.

12.2 Structure and Scantlings of Structural Members

12.2.1 The seating is to consist, in general, of two vertical girders and horizontal bed plates intended for fastening the machinery or boiler – directly or by means of seating frames. The girders and horizontal bed plates are to be stiffened with brackets or supports where necessary.

12.2.2 When designing the seatings, provision is to be made for avoiding abrupt changes of dimensions. Where this is impracticable, a smooth transition between seating members of different dimensions and between seating members and bottom, sides and deck members is to be provided.

12.2.3 When the single bottom side girder is also considered as the seating web, its thickness is not to be less than that required for the seating web and the centre bottom girder. The height of the bottom floors is to be increased according to the structure of the machinery seatings. The height of the floors between the seating longitudinal girders is not to be less than 0.65 of the height required in the centre plane.

12.2.4 When the bed plates of the main engine and thrust bearing form a part of the inner bottom plating, they are to be supported by two parallel bottom girder webs or by a girder and half-girder webs. The thickness of the girder webs at the bed plate within 0.2 of their height is to be equal to that of the bed plate or the webs within their full height may be of the thickness required for the seating web.

Longitudinal stiffeners of bed plate are to be fitted between webs. The scantlings of those stiffeners are to be the same as those determined above for the upper parts of girders.

The application of one web only on the bed plate is possible for engines of low power upon the PRS agreement only.

In each case the bed plate is to be strengthened within its total length by transverse brackets fitted between the adjacent bolts at equal distances from their centres.

12.2.5 Where longitudinal girders of the seating are fitted to the strength deck, they are to be in line with the underdeck stiffeners.

12.2.6 The scantlings of seating structure members are a function of the mass of the machinery or boiler or a function of the rated power of the machinery motor.

The thickness t of the seating structure members is not to be less than:

– for low-speed engine, boiler or machinery (specified in Table 12.2.6):

$$t = c_1 \sqrt[3]{M} + t_m, \quad \text{[mm]} \qquad (12.2.6\text{-}1)$$

M – mass of engine, boiler, or other machinery in operating condition, [t];

c_1 – factor as given in Table 12.2.6;

t_m – the thickness allowance, [mm], depending on the mass M. The following values of t_m are to be taken:

$t_m = 0$ for $M > 200$,
$t_m = 1$ for $100 < M \le 200$,
$t_m = 2$ for $50 < M \le 100$,
$t_m = 3$ for $20 < M \le 50$,
$t_m = 4$ for $M \le 20$.

Table 12.2.6
Values of factor c_1

Machinery	Members of seating structure		
	Horizontal plates (bed plates)	Web plates of longitudinal girders[1)]	Brackets, including console brackets[2)]
Main internal combustion engine	4.65	3.00	2.50
Turbine propulsion plants, electric motors and generating sets	4.15	2.70	2.70
Boiler	3.65	2.40	2.40

1) In the case of the seating with two longitudinal girders at each side of the engine, the thickness of outer girder web plates may be equal to that of the brackets.

2) Console brackets – trapezoid brackets, three edges of which are attached to the seating structure members.

– for medium-speed engine:

$$t = c_2 \sqrt[3]{N}, \quad [\text{mm}] \qquad (12.2.6\text{-}2)$$

$c_2 = 2.3$ for horizontal plate (bed plate),
$c_2 = 1.6$ for web plates of inner girders of seating,
$c_2 = 1.3$ for web plates of outer girders, consoles and brackets;
N – power rating of the engine, [kW].
Scantlings for high-speed engines will be considered by PRS separately.

13 LOCAL STRENGTH AND BUCKLING CONTROL OF THE STRUCTURE

13.1 General

13.1.1 Application

13.1.1.1 The requirements of the present Chapter apply to the scantlings of plates, stiffeners, simple girders, pillars, supporting members, as well as to stiffener and girder end brackets. The above requirements, except those concerning the minimum scantlings, result from the local design loads on members in question, without those considered in *Part C*.

13.1.1.2 For plates, stiffeners and simple girders which take part in the local strength and, in addition, in the longitudinal strength of ship, the requirements concerning the buckling control of these members are given.

13.1.2 Definitions

A – required cross-sectional area, [cm^2];
A_s – required web cross-sectional area, [cm^2];
b – breadth of plating supported by a girder or stiffener in question, [m];
b_m – breadth of the free flange, [mm];

$$f = \frac{5.7\left(M_s + M_w\right)}{W_1} \qquad (13.1.2)$$

h_s – web height, [mm];
l – span of a stiffener or a simple girder according to 3.2.1, [m];
L_1 = L_0, but not more than 120 m;
M_s – the maximum value of still water bending moment, obtained as the result of analysis of various load conditions, [kNm]; the assumed value of M_s is not to be less than 0.5 M_{so} (M_{so} – design minimum still water bending moment, [kNm], determined according to 15.4);
M_w – Rule wave bending moment, [kNm], determined according to 15.5;
p – design pressure (see Chapter 17), [kPa];
s – stiffener spacing measured along the plating, [m];
t – required thickness of the plating, [mm];
t_k – corrosion addition (see 2.5), [mm];
t_m – flange thickness of stiffener or girder, [mm]; for bulb section, the mean thickness of the bulb is to be used;
t_s – web thickness, [mm];
W – required section modulus of a stiffener or a girder, [cm^3];
W_1 – the smallest section modulus of the ship's hull, determined according to 15.7, [cm^3]. It should be determined for strength deck – if the member in question is above the horizontal neutral axis of hull cross section, or for the outer bottom – if the considered member is below this axis;

w_k – section modulus corrosion factor (see 13.5.2.5);
z_a – vertical distance from the baseline or the deck line to the point in question below or above the neutral axis, respectively, [m];
z_n – vertical distance from the baseline or the deck line to the neutral axis of the hull girder, whichever is applicable, [m];
σ – allowable normal stress, [MPa];
σ_c – critical compressive buckling stress, [MPa];
σ_E – ideal elastic compressive buckling stress, [MPa];
τ – allowable shear stress, [MPa];
τ_c – critical shear stress, [MPa];
τ_E – ideal elastic buckling shear stress, [MPa].

13.1.3 Explanations

D e s i g n l o a d p o i n t – point at which the design pressure is to be determined according to the requirements of Chapter 17.

The location of the load point is to be determined as follows:
– for horizontally stiffened plates: in the midpoint of non-stiffened field;
– for vertically stiffened plates: at the lower edge of the plate for unsupported edges (e.g. when the thickness is changed within the plate area), or in half of the stiffener spacing above the lower edge for supported edges;
– for stiffeners: in span midpoint; where the pressure distribution along the stiffener span is not linear, the design pressure is to be determined in the middle of the span and as the arithmetic mean of pressures at the stiffener ends, whichever is the greater;
– for girders: in the midpoint of the plating area supported by a girder.

13.2 Minimum Thickness

13.2.1 General Requirements

The minimum thickness of hull structural members is not to be less than that calculated from the formula:

$$t = t_0 + \frac{k_1 L_1}{\sqrt{k}} + t_k, \quad [\text{mm}] \tag{13.2.1}$$

t_0, k_1 – parameters; the values thereof for particular hull members are given below in paras. 13.2.2 to 13.2.5;
k – material factor depending on the material yield stress (see 2.2.1).

13.2.2 Bottom Structure

13.2.2.1 Keel plate: $t_0 = 7.0$; $k_1 = 0.05$.

13.2.2.2 Outer bottom and bilge plating: $t_0 = 5.0$; $k_1 = 0.04$.

13.2.2.3 Inner bottom plating:

t_0 = 7.0 – below hatchways in storage spaces when ceiling of wood or other approved material is not fitted,

t_0 = 6.0 – elsewhere if ceiling is not fitted,

t_0 = 5.0 – in general where ceiling is fitted;

k_1 = 0.03.

13.2.2.4 Floors and bottom longitudinal girders, supporting plates and brackets:

t_0 = 6.0;

k_1 = 0.04 – for centre girder in area $z \le 2$ m,

k_1 = 0.02 – for the centre girder in area $z > 2$ m and other girders.

13.2.2.5 Webs and flanges of longitudinal and transverse frames of the inner and outer bottom, stiffeners of floors, longitudinal girders and supporting plates:

t_0 = 5.0;

k_1 = 0.03 – in forepeak and after peak tanks,

k_1 = 0.02 – elsewhere.

13.2.3 Side Structure

13.2.3.1 Side plating:

t_0 = 5.0;

k_1 = 0.04 – within $z \le z_0$, where $z_0 = T + 4.6$ m; within $z > z_0$, the k_1 value may be reduced by 0.01 for each 2.3 m of z increase, but $k_1 \ge 0.01$,

k_1 = 0.06 – for side plating connected to sternframe.

13.2.3.2 Webs and flanges of longitudinal and transverse frames:

t_0 = 5.0;

k_1 = 0.02 – in forepeak and after peak tanks,

k_1 = 0.01 – elsewhere.

13.2.3.3 Girders: flanges, webs, their stiffeners and brackets:

t_0 = 5.0;

k_1 = 0.03 – in forepeak and after peak tanks,

k_1 = 0.02 – in ballast and cargo tanks,

k_1 = 0.01 – elsewhere.

13.2.4 Deck Structure

13.2.4.1 Strength deck plating:

t_0 = 5.5 – for exposed deck or storage spaces not sheathed with wood or other approved materials,

t_0 = 5.0 – for exposed deck or storage spaces sheathed with wood or other approved materials, as well as within accommodation spaces;

k_1 = 0.02 – for single-deck ships,

k_1 = 0.01 – for ships having two continuous decks within $z > 0.7\,H$,

k_1 = 0.01 – for exposed deck within $x \geq 0.3\ L_0$ (minimum value),
k_1 = 0.00 – for ships having more than two continuous decks within $z > 0.7\ H$.

13.2.4.2 The plating of decks situated above or below the strength deck :
t_0 – as given above for the strength deck;
k_1 = 0.01 – for the deck situated within $z > 0.7\ H$ in ships with two continuous decks satisfying the condition $z > 0.7\ H$,
k_1 = 0.01 – for the deck of the first tier of superstructure or deckhouse in single-deck ship if the length of the superstructure or deckhouse situated amidships ($-0.2\ L_0 \leq x \leq 0.2\ L_0$) exceeds $0.2\ L_0$,
k_1 = 0.00 – for other decks.

13.2.4.3 Webs and flanges of deck longitudinals and beams:
t_0, k_1 – as given above for side frames.

13.2.4.4 Flanges, webs, web stiffeners and deck girder brackets:
t_0, k_1 – as given above for side girders.

13.2.5 Bulkhead Structure

13.2.5.1 Bulkhead plating:
t_0 = 7.0 – for forepeak and after peak tanks,
t_0 = 5.0 – elsewhere;
k_1 = 0.02 – in forepeak and after peak tanks,
k_1 = 0.01 – elsewhere.

13.2.5.2 Webs and flanges of longitudinal, vertical and transverse stiffeners water ballast and storage tank bulkheads, wash bulkheads:
$t_0 = 5.0$; k_1 – as given above for bulkhead plating.

13.2.5.3 Webs, flanges, stiffeners and brackets of bulkhead girders:
t_0, k_1 – as given above for side girders.

13.3 Buckling Control of Structural Elements

13.3.1 General Requirements

13.3.1.1 The plating and longitudinal girders and stiffeners of the outer and inner bottom, sides, strength deck and longitudinal bulkheads taking part in the hull girder longitudinal strength and situated amidships are to be checked for buckling strength in uni – axial compression.

13.3.1.2 Within transition zones between midship portion of the hull and the peaks, the buckling strength of structural elements specified in 13.3.1.1 need not be checked. Such check may be required, however, in the case of structural discontinuity in these zones, uneven distribution of stores, ballast or equipment loads along ship's length, as well as in the case of large flare of sides in the ship's forebody.

13.3.1.3 For ships in which the hulls are subjected to considerable shear forces, the plating of sides and longitudinal bulkheads taking part in the hull girder longitudinal strength are to be checked for shear buckling strength.

13.3.1.4 Compliance with compression buckling strength and shear buckling strength requirements do not preclude special consideration, by PRS, of buckling strength of plates and longitudinal structural elements which are simultaneously subjected to compression and shear. This applies also to bi-axial compression, as well as bi-axial compression and shear.

13.3.1.5 The required scope of buckling control of structural members not specified in 13.3.1.1 to 13.3.1.4 is given in detailed requirements referring to those members.

13.3.2 Buckling Strength Criteria and Design Stress Values

13.3.2.1 For members or their parts subject to check for buckling strength in uni – axial compression, the following condition is to be complied with:

$$\sigma_c \geq c\sigma_r \qquad (13.3.2.1)$$

σ_c – critical compressive buckling stress determined according to 13.3.2.2, taking into account the final scantlings of the member in question, [MPa];

σ – design compressive stress determined according to 13.3.2.7, [MPa];

c – coefficient expressing the margin of critical stress in relation to the expected compressive stress:

c = 1 – for plate panels and girder or stiffener webs,

c = 1.1 – for stiffeners.

13.3.2.2 Critical stress in uni-axial compression for a member in question is to be determined from the formula:

$$\sigma_c = \sigma_E, \quad [\text{MPa}] \quad \text{if} \quad \sigma_E \leq \frac{R_e}{2} \qquad (13.3.2.2\text{-}1)$$

$$\sigma_c = R_e\left(1 - \frac{R_e}{4\sigma_E}\right), \quad [\text{MPa}] \quad \text{if} \quad \sigma_E > \frac{R_e}{2} \qquad (13.3.2.2\text{-}2)$$

σ_E – ideal elastic compressive buckling stress, [MPa], determined according to 13.4.3 and 13.5.3.

13.3.2.3 For plate panels subject to check for shear buckling strength, the following condition is to be complied with:

$$\tau_c \geq \tau_r \qquad (13.3.2.3)$$

τ_c – critical shear stress of plate panel determined according to 13.3.2.4, [MPa];

τ_r – design compressive shear stress of plate panel determined according to 13.3.2.8, [MPa].

13.3.2.4 Critical shear stress τ_c for plate panel is to be determined from the formula:

$$\tau_c = \tau_E, \quad \text{[MPa]} \quad \text{if} \quad \tau_E < 0.5\,\tau_{pl} \qquad (13.3.2.4\text{-}1)$$

$$\tau_c = \tau_{pl}\left(1 - \frac{\tau_{pl}}{4\tau_E}\right), \quad \text{[MPa]} \quad \text{if} \quad \tau_E > 0.5\,\tau_{pl} \qquad (13.3.2.4\text{-}2)$$

$$\tau_{pl} = \frac{R_e}{\sqrt{3}}, \quad \text{[MPa]} \qquad (13.3.2.4\text{-}3)$$

τ_E – ideal elastic buckling shear stress, [MPa], determined according to 13.4.3.

13.3.2.5 For plate panels subject to complex stresses (uni-axial or bi-axial compressive stresses combined with shear stresses), the following condition is to be complied with:

$$\sigma_{ec} \geq \sigma_{er}$$

σ_{ec} – critical equivalent buckling stress determined according to 13.3.2.6, [MPa],
σ_{er} – design equivalent buckling stress determined according to 13.3.2.9, [MPa].

13.3.2.6 Critical equivalent buckling stress for plate panels subject to complex stresses is to be determined from the formula:

$$\sigma_{ec} = \sigma_{eE}, \quad \text{if} \quad \sigma_{eE} \leq \frac{R_e}{2} \qquad (13.3.2.6\text{-}1)$$

$$\sigma_{ec} = R_e\left(1 - \frac{R_e}{4\sigma_{eE}}\right), \quad \text{if} \quad \sigma_{eE} > \frac{R_e}{2} \qquad (13.3.2.6\text{-}2)$$

σ_{eE} – ideal elastic equivalent buckling stress for plate panels subject to complex stresses, [MPa], determined according to 13.4.3.7.

13.3.2.7 The compressive stress σ_r amidship, due to hull girder bending, which is the basis of the requirements for buckling strength of plate panels, longitudinal girders walls and longitudinal stiffeners subject to uni-axial compression, is to be determined from the formula:

$$\sigma_r = \frac{M_s + M_w}{I_n} z \cdot 10^5, \quad \text{[MPa]} \qquad (13.3.2.7\text{-}1)$$

The value of σ_r taken for buckling strength analysis of structural members is to comply with following condition:

$$\sigma_r \geq 30\,k, \text{ [MPa]}, \qquad (13.3.2.7\text{-}2)$$

M_s – design still water bending moment in the considered transverse cross-section, determined according to 15.4, [kNm];
M_w – wave bending moment in the considered transverse cross-section, determined according to 15.5, [kNm];

I_n – moment of inertia of the considered transverse cross-section of the hull, determined according to 15.3 and 15.7, [cm^4];
z – vertical distance from neutral axis of the cross-section to the considered point, [m];
k – material factor, determined according to 2.2.1.

M_s and M_w are to be assumed as equal to design values of sagging or hogging moment depending on the position of the considered girder or stiffener above or below the neutral axis of transverse cross-section of the hull.

If in still water, the ship is hogged, then the value of design moment ($M_s + M_w$) will be specially considered by PRS.

In ships with wide openings in the strength deck the compressive stress σ_r being the result of simultaneous hull girder bending in vertical and horizontal planes and the torsion, are subject to special consideration by PRS.

The check of buckling strength of plating panels and girder webs subjected to uni-axial compression does not waive the necessity of checking buckling strength of the elements subject to complex stresses according to 13.3.2.9 and 13.3.2.10.

13.3.2.8 For ships without longitudinal bulkheads, shear stresses τ_r in the side plating due to hull girder shear, which is the basis of the requirements for shear buckling strength of plate panels, is to be determined from the formula:

$$\tau_r = \frac{0.5\left|Q_s + Q_w\right|}{t}\frac{S_n}{I_n}\cdot 10^2 , \quad \text{[MPa]} \qquad (13.3.2.8)$$

where:
Q_s, Q_w, S_n, t, I_n – see 15.1.2.
t – side plating thickness, [mm].

Stresses τ_r for ships with longitudinal bulkheads are subject to special consideration by PRS.

13.3.2.9 The design values of equivalent stresses in plate panels or in girder webs are to be calculated from the formula

$$\sigma_e = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau^2} , \quad \text{[MPa]} \qquad (13.3.2.9)$$

σ_x, σ_y, τ – stresses in panel, [MPa], as shown in Fig. 13.3.2.9.

Compressive stresses σ_x or σ_y are to be taken as positive. If σ_x or σ_y is tensile stress then 0 values are to be taken in formula 13.3.2.9. Stresses σ_x, σ_y, τ are to be calculated disregarding cut-outs in the plate panel.

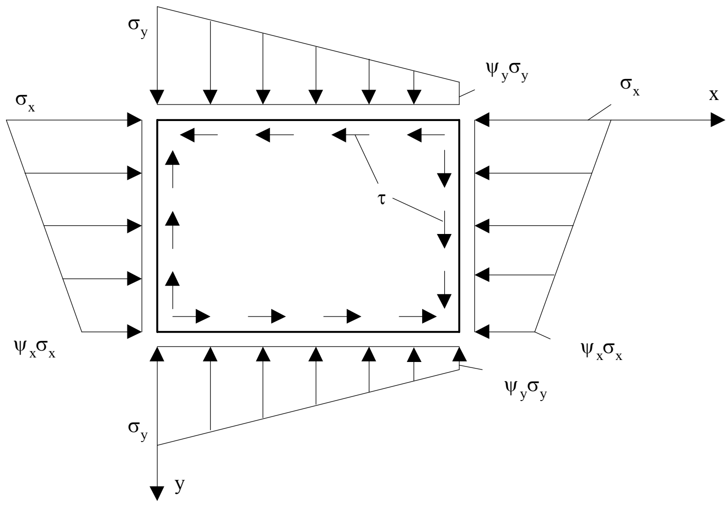


Fig. 13.3.2.9

13.3.2.10 Stress values applied in evaluation of buckling strength of a construction, in cases other than those specified in 13.3.2.7 and 13.3.2.8, are to be calculated within zone strength analysis of the construction according to the provisions of Chapter 14.

In case of hull girders and plate panels, in which significant values of bi-axial compressive stresses σ occur or of shear stresses τ acting simultaneously with normal stresses, the buckling strength for combined in-plane loads for design stress values determined according to 13.3.2.9 is to be checked.

For longitudinal structural members, the stresses from hull girder bending or torsion determined according to 13.3.2.7 are to be taken into account.

13.4 Hull Plating

13.4.1 General Requirements

The assumed thickness of the plating is to comply with the following requirements:

– minimum thickness of structural members given in 13.2,
– bending strength of plates given in 13.4.2,
– buckling strength of plate panels specified in 13.3 in compliance with recommendations given in 13.4.3.

13.4.2 The Thickness of Plating

13.4.2.1 The thickness of plating subjected to lateral pressure is to be calculated from the formula:

$$t = 18\, k_a\, s \sqrt{\frac{p}{\sigma}} + t_k\,, \quad \text{[mm]} \qquad (13.4.2.1\text{-}1)$$

$$k_a = \left(1 - 0.27\frac{s}{l}\right)^2 ; \qquad (13.4.2.1\text{-}2)$$

k_a need not be greater than 0.88,

p – design pressure acting on the plate in question, [kPa], to be determined according to recommendations specified in 17.6;

σ – allowable normal bending stress calculated according to 13.4.2.2 or 13.4.2.3, [MPa].

13.4.2.2 The allowable stresses for plating fitted amidships and taking part in the hull longitudinal strength are to be determined according to Table 13.4.2.2. The assumed value is not to exceed σ_{max} = 160 k, [MPa].

For plate panels in way of peaks, the value of σ = 160 k, [MPa] is to be taken.

Note: The value of σ varies linearly between the midship and extreme parts of the ship.

Table 13.4.2.2
Allowable stress for plating amidships

Item	Plating in way of:	σ, [MPa]
1	outer bottom	
1.1	longitudinally stiffened	120 k
1.2	transversely stiffened	175 k – 120 f
2	inner bottom	
2.1	longitudinally stiffened	140 k
2.2	transversely stiffened	200 k – 110 f, but not more than 140 k
3	sides[1)]	
3.1	longitudinally stiffened	140 k
3.2	transversely stiffened	120 k
4	longitudinal bulkheads[1)]	
4.1	longitudinally stiffened	160 k
4.2	transversely stiffened[2)]	140 k
5	strength deck	
5.1	longitudinally stiffened	120 k
5.2	transversely stiffened	175 k – 120 f, but not more than 120 k

1) Values of σ in way of the neutral axis of the hull cross-section are given. Above and below the neutral axis, the σ is to be linearly reduced to the values for the deck and bottom plating assuming the same stiffening direction and the material factor as for the plating in question.

2) Where the longitudinal bulkhead forms the tank boundary and design pressure $p = p_{10}$ or $p = p_{12}$ was applied, the allowable stress may be increased to σ = 160 MPa.

13.4.2.3 The allowable stresses σ may be taken equal to 160 k for the plating of transverse bulkheads, decks below the strength deck and for the side and deck plating in short superstructures and deckhouses.

The allowable stresses for transverse bulkhead plating for flooded compartment may be taken equal to 220 k, [MPa].

13.4.2.4 The thickness of side and longitudinal bulkhead plating in way of supports of horizontal girders on the transverse bulkheads is to be adequately increased.

13.4.3 Buckling Strength of Plating and Girder Webs

13.4.3.1 The provisions of the present sub-chapter apply to determining the ideal elastic buckling stresses for actual dimensions of the plate panels subjected to uni-axial compression, shear, or combined in-plane loads.

13.4.3.2 The plate panels and girder webs of the outer and inner bottom, sides, strength deck and longitudinal bulkheads taking part in the hull girder longitudinal strength are to comply with the requirements of 13.3 for the buckling strength of uni-axial compressed plates, the ideal elastic buckling stress σ_E being calculated according to 13.4.3.4 and τ_E calculated according to 13.4.3.5, if applicable.

All panels of hull plating, bulkheads, walls and girder webs, in cases specified in 13.3.2.10, are to comply with buckling strength criteria for combined in-plane loads, given in 13.3.2.5 unless PRS allows the application of requirements of 13.4.3.3 to certain panels.

13.4.3.3 Elastic buckling of panels may be accepted upon special consideration by PRS. In such cases the evaluation of the hull longitudinal strength is to be based on the reduced effective width of the plate panels.

13.4.3.4 The ideal elastic buckling stress σ_E for compression of plate fields within the adjacent supporting contour is to be determined from the formula:

$$\sigma_E = 0.9\, m\, E \left[\frac{t_n}{1000\, s}\right]^2, \quad \text{[MPa]} \qquad (13.4.3.4\text{-}1)$$

For plate fields stiffened longitudinally (parallel to compressive stress):

$$m = \frac{8.4}{k_2 + 1.1} \qquad (13.4.3.4\text{-}2)$$

For plate fields stiffened transversely (perpendicularly to compressive stress):

$$m = c\left[1 + \left(\frac{s}{l}\right)^2\right]^2 \frac{2.1}{k_2 + 1.1} \qquad (13.4.3.4\text{-}3)$$

E – see A/2.2;
t_n – net thickness of plating panel, [mm], taking into account the standard deduction, determined from Table 13.4.3.4;
s – length of shorter side of plate field, [m];
l – length of longer side of plate field, [m];
c = 1.30 – where the plating is stiffened with bottom floors or deep girders,
c = 1.21 – where stiffeners are angles or T-sections,
c = 1.10 – where stiffeners are bulb flats,

c = 1.05 – where stiffeners are flat bars;

k_2 – is the ratio of the smallest and the largest compressive stress σ (see Fig. 13.4.3.4).

The assumed value of k_2 is to meet the condition $0 \le k_2 \le 1$.

For plates with cut-outs, σ_E is to be corrected according to 13.4.3.8, 13.4.3.10 and 13.4.3.11.

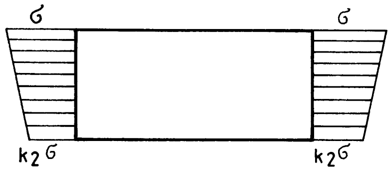


Fig. 13.4.3.4 Definition of factor k_2

Table 13.4.3.4

Item	Structure	Standard deduction, [mm]	Extreme values min – max, [mm]
1	Vertical bulkheads of spaces subjected to pressure of ballast or liquid stores at one side	0.05 t	0.5 – 1
2	Horizontal boundaries of spaces subjected to pressure of ballast or liquid cargo at one side, vertical bulkheads of spaces subjected to pressure of ballast or liquid stores at both sides	0.10 t	2 – 3
3	Horizontal boundaries of spaces subjected to pressure of ballast or liquid stores at both sides	0.15 t	2 – 4

13.4.3.5 The ideal elastic buckling shear stress τ_E of plate fields within the adjacent supporting contour is to be determined from the formula:

$$\tau_E = 0.9\,k_t\,E\left(\frac{t_n}{1000s}\right)^2, \quad \text{[MPa]} \qquad (13.4.3.5\text{-}1)$$

$$k_t = 5.34 + 4\left(\frac{s}{l}\right)^2 \qquad (13.4.3.5\text{-}2)$$

For E, t_n, s, l – see 13.4.3.4.

For plates with cut-outs, τ_E is to be corrected according to 13.4.3.9, 13.4.3.10 and 13.4.3.11.

13.4.3.6 For plate field subjected to combined in-plane load (Fig. 13.3.2.9), the values of ideal elastic buckling stresses σ_{xE}, σ_{yE}, τ_E are to be determined from the formula:

$$\frac{\sigma'_{xE}}{\sigma_{xE}} + \frac{\sigma'_{yE}}{\sigma_{yE}} + \left(\frac{\tau'_{E}}{\tau_{E}}\right)^2 = 1 \qquad (13.4.3.6)$$

where:

σ'_{xE} – value of ideal elastic buckling stress at compression towards axis x, in case of combined in-plane load, as shown in Fig. 13.3.2.9;

σ_{xE} – value of ideal elastic buckling stress at uni-axial compression towards axis x (Fig. 13.4.3.4), calculated as σ_E according to 13.4.3.4;

$\sigma'_{yE}, \sigma_{yE}$ – as σ'_{xE}, σ_{xE}, but at compression towards axis y;

τ'_{E} – value of ideal elastic shear stress, in case of combined in-plane load, as shown in Fig. 13.3.2.9;

τ_{E} – value of ideal elastic shear stress, calculated according to 13.4.3.5.

When calculating the values of σ'_{xE}, σ'_{yE}, and τ'_{E} according to formula 13.4.3.6, they are to be assumed to be directly proportional to the values of stresses σ_x, σ_y, τ determined according to 13.3.2.9 and 13.3.2.10. Compressive stresses are to be positive. Where σ_x or σ_y are tensile, σ'_{xE}/σ_{xE} or σ'_{yE}/σ_{yE} are to be taken equal to 0 in formula 13.4.3.6.

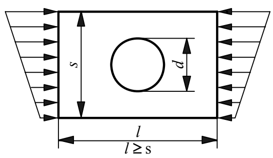
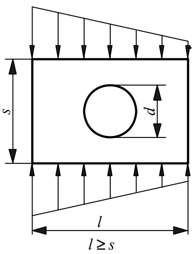
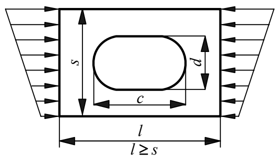
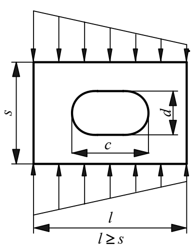
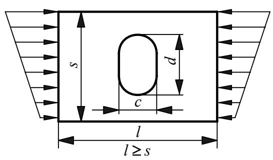
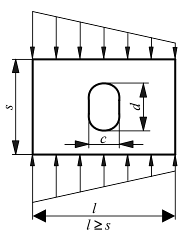
13.4.3.7 The values of equivalent ideal elastic stress for plate subjected to combined in-plane load are to be calculated from the formula:

$$\sigma_{eE} = \sqrt{(\sigma'_{xE})^2 + (\sigma'_{yE})^2 - \sigma'_{xE}\sigma'_{yE} + 3(\tau'_{E})^2} \qquad (13.4.3.7)$$

$\sigma'_{xE}, \sigma'_{yE}, \tau'_{E}$ – ideal elastic stresses calculated according to 13.4.3.6, they are to be non-negative numbers.

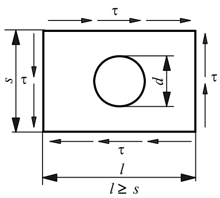
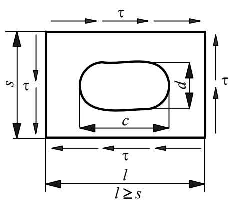
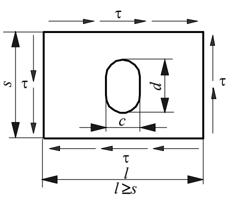
13.4.3.8 Where a circular or oval opening has been cut out in the centre of the panel field, the values of σ_E calculated according to 13.4.3.4 are to be corrected through multiplying by non-dimensional factor r_k of values determined acc. to Table 13.4.3.8.

Table 13.4.3.8
Correction factors for panels with openings subject to uni-axial compression

Item	Type of opening and direction of compression	Value of r_k and scope of application
1	2	3
1		$r_k = 1.17 - 1.41\frac{d}{s} + 1.17\left(\frac{d}{s}\right)^2$, for: $0.3 \le \frac{d}{s} \le 0.7$
2		$r_k = 0.85$ for: $0.3 \le \frac{d}{s} \le 0.7$
3		$r_k = 0.66$ for $1 \le \frac{l}{s} \le 2$, $r_k = 0.76$ for $\frac{l}{s} > 2$ Values of r_k valid for: $0.3 \le \frac{d}{s} \le 0.7$ and $1.25 \le \frac{c}{d} \le 2$
4		$r_k = 0.82$ for $1 < \frac{l}{s} \le 2$, $r_k = 0.66$ for $\frac{l}{s} > 2$ Values of r_k valid for: $0.3 \le \frac{d}{s} \le 0.75$ and $1.25 \le \frac{c}{d} \le 2$
5		$r_k = 0.78$ for $1 \le \frac{l}{s} \le 2$, $r_k = 0.85$ for $\frac{l}{s} > 2$ Values of r_k valid for: $0.3 \le \frac{d}{s} \le 0.75$ and $1.25 \le \frac{d}{c} \le 2$
6		$r_k = 0.74 + 0.03\frac{l}{s}$, for: $0.3 \le \frac{d}{s} \le 0.75$ and $1.25 \le \frac{d}{c} \le 2$

13.4.3.9 Where a circular or oval opening has been cut out in the centre of the panel field, the values of τ_E calculated according to 13.4.3.5 are to be corrected through multiplying by non-dimensional factor r_k of values determined acc. to Table 13.4.3.9.

Table 13.4.3.9
Correction factors for panels with openings subject to shear stresses only

Item	Type of opening	Value of r_k and scope of application
1		$r_k = 1.17 - 2.32\frac{d}{s} + 1.31\left(\frac{d}{s}\right)^2$, for: $0.3 \le \frac{d}{s} \le 0.7$
2		$r_k = 1.17 - 2.32\frac{d}{s} + 1.31\left(\frac{d}{s}\right)^2 + 0.16\left(1.75 - \frac{c}{d}\right) + \Delta r$ for: $1.25 \le \frac{c}{d} \le 2$, $0.3 \le \frac{d}{s} \le 0.7$ where: $\Delta r = 0.08\frac{l}{s} \le 2.5$; for $1.5 < \frac{l}{s} < 2.5$; $\Delta r = 0$ – for other values $\frac{l}{s}$.
3		$r_k = 1.17 - 2.32\frac{d}{s} + 1.31\left(\frac{d}{s}\right)^2 + 0.22\left(1 - \frac{c}{d}\right) + \Delta r$ for $0.5 \le \frac{c}{d} \le 0.75$, $0.3 \le \frac{d}{s} \le 0.7$ where: $\Delta r = 0.3\frac{l}{s} - 0.06\left(\frac{l}{s}\right)^2 - 0.25$ for $\frac{l}{s} \le 2.5$; $\Delta r = 0.125$ for $\frac{l}{s} > 2.5$.

13.4.3.10 For the plate panels with circular or oval opening cut out in the centre of the panel field and strengthened with a flat bar welded around to the edge of the opening symmetrically to the panel plane, the ideal elastic stresses calculated according to 13.4.3.8 or 13.4.3.9 may be corrected in the following way:

a) where the thickness of the flat bar is not less than the panel plate thickness and the flat bar height is not less than four times the thickness of panel plate, then for the plate panel subject to uni-axial compression:

$$r_k = 1 \qquad (13.4.3.10\text{-}1)$$

b) for the plate panel subject to pure shear only, strengthened in way given in a), value r_k according to Table 13.4.3.9 are to be additionally multiplied by the factor:

$$r_u = 0.3 + 2.0\frac{d}{s} + 0.2\frac{c}{d} + 0.6\frac{s}{l} \qquad (13.4.3.10\text{-}2)$$

l, s, c, d – dimensions as shown in figures in Table 13.4.3.9,
$c = d$ – for a circular cut-out.

c) where, in pure shear, the opening edge has been strengthened with a flat bar of thickness not less than two times the panel plate thickness and the height not less than four times panel plate thickness, then:

$$r_k = 1 \qquad (13.4.3.10\text{-}3)$$

13.4.3.11 Where the panel with a circular or oval opening in the centre has been strengthened, as shown in Fig. 13.4.3.11, with flat bars of thickness not less than the panel plate thickness and the height not less than four times the panel plate thickness, then for panels subjected to pure shear, the values of τ_E calculated according to 13.4.3.5 may be corrected, in relation to the requirements of 13.4.3.9, by multiplying the value of r_k (calculated according to Table 13.4.3.9) by factor r_u determined in the following way:

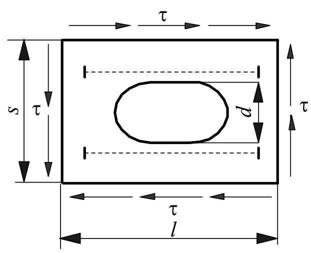


Fig. 13.4.3.11

$$r_u = \left(2 - \frac{d}{b}\right)\left(0.6 + 0.1\frac{h}{t}\right) \qquad (13.4.3.11)$$

where:
d , s – dimensions as shown in Fig. 13.4.3.11;
h ,t – height and thickness of flat bars, [mm].

For the plate panels subject to uni-axial compression, strengthened as specified above, stresses σ_E for each of three parts of the panel, formed due to the application of flat bars (Fig. 13.4.3.11) may be calculated acc. to 13.4.3.4, i.e. assuming that flat bars are the stiff support for the panel plate and ignoring the opening. The a/m flat bars are then to meet the requirements of 13.5.3.1 in association with 13.5.3.2 and 13.5.3.3.

13.5 Stiffeners

13.5.1 General Requirements

13.5.1.1 The scantlings of various stiffeners cross-sections are to be so selected as to comply with the following requirements:
- the minimum thickness of structural members given in 13.2,
- the bending strength of a stiffener due to lateral load given in 13.5.2,
- stiffener buckling strength, given in 13.3, taking into account 13.5.3, where applicable.

13.5.1.2 The scantlings of stiffeners subjected to the axial compressive loads are to be determined according to 13.7.3.

13.5.2 Section Modulus

13.5.2.1 The net section modulus, i.e. after deduction of corrosion allowances according to 2.5 (see also 13.5.2.5) for:
- longitudinal and transverse stiffeners of the outer and inner bottom and of sides, as well as stiffeners of tight floors and longitudinal girders;
- longitudinal and transverse stiffeners of decks and platforms,
- longitudinal and transverse, horizontal and vertical stiffeners of bulkheads and partitions subjected to lateral load,

is to be not less than:

$$W = \frac{1000\, l^2 s\, p}{m\, \sigma}, \quad [\text{cm}^3] \qquad (13.5.2.1)$$

but not less than 15 cm^3.

m – bending moment factor according to 13.5.2.2 (see also 13.5.2.4), as well as Table 5.2.3.3.

The allowable stresses σ are to be determined as follows (see also 13.5.2.3):
- for longitudinal stiffeners in the midship part of ship: from Table 13.5.2.1 and the assumed values are not to exceed σ_{max} = 160 *k*, [MPa];
- for longitudinal stiffeners in ship ends: σ = 160 *k*, [MPa]; the value of σ may be varied linearly between the midship part and the ship's ends;
- for transverse stiffeners (vertical and horizontal), including collision bulkhead stiffeners : σ = 160 *k*, [MPa];
- for stiffeners of other watertight bulkheads : σ = 220 *k*, [MPa].

σ_{dp} – stresses in stiffeners face plate due to double bottom bending in way of the considered area, [MPa], determined according to the requirements of Chapter 14.

The applied values of σ_{dp} are not to be less than σ_{dp} = 15 *k*, [MPa].

Table 13.5.2.1
Allowable bending stress for longitudinal stiffeners in the midship part of ship

Item	Longitudinal stiffener in way of:	σ, [MPa]
1 1.1 1.2	Outer bottom: – in double bottom – in single bottom	 $225\,k - 130\,f - \sigma_{dp}$ $225\,k - 130\,f$
2	Inner bottom	$225\,k - 100\,f - \sigma_{dp}$
3	Tight longitudinal girders	$225\,k - 110\,f$
4	Sides	$225\,k - 130\,f\,(z_n - z_a)\,/\,z_n$ max 130 k in single–deck ships
5	Longitudinal bulkheads	$225\,k - 130\,f\,(z_n - z_a)\,/\,z_n$
6 6.1 6.2	Deck: – strength deck, long superstructure and effective deckhouse above the strength deck – continuous decks below the strength deck	 $225\,k - 130\,f$ $225\,k - 130\,f\,(z_n - z_a)\,/\,z_n$

13.5.2.2 The following values of the bending moment factor m are to be assumed in formula 13.5.2.1:
$m = 12$ for continuous longitudinal stiffeners,
$m = 10$ for discontinuous longitudinal and transverse stiffeners,
$m = 7.5$ for free supported vertical stiffeners,
$m = 10$ for vertical stiffeners which may be considered fixed at both ends.

For watertight bulkhead structures exposed to sea water pressure in flooded conditions:
$m = 16$ for stiffener fixed at both ends,
$m = 12$ for stiffener fixed at one (lower) end and simply supported at the other,
$m = 8$ for stiffener simply supported at both ends.

Note: The above values of m for watertight bulkheads have been based on the assumption that plastic hinges occur at fixed supports and are not to be compared with the bending moment factor m corresponding to elastic bending.

13.5.2.3 The stiffener and plating are generally to be of steel with the same yield stress. If the stiffener is of a greater value of yield stress than that of the plating, σ corresponding to the plate material is to be applied. If the calculated stress in the plating is less than the applicable limit, the value of σ for the stiffener may be multiplied by a factor not greater than k_u / k_p (k_u – material factor for stiffener; k_p – material factor for plating).

13.5.2.4 In special cases, stiffeners may be snipped at the ends if the thickness of plating supported by the stiffener is not less than:

$$t = 1.25\sqrt{\frac{(1-0.5s)\,s\,p}{k}} + t_k\,, \quad \text{[mm]} \qquad (13.5.2.4)$$

In this case the section modulus is to be calculated from formula 13.5.2.1 taking:

$m = 8$, $\sigma = 145\ k$, [MPa].

13.5.2.5 Design section moduli of stiffeners (within region A or B according to sub-chapter 2.5) are to be increased in relation to values W, calculated from formula 13.5.2.1, due to corrosion additions.

For stiffeners welded of web and face plate or made of flat bars, adequate value of t_k (see 2.5) is to be added to the web and face plate thicknesses to ensure the required value of net section modulus.

For stiffeners made of rolled sections, the design section modulus may be calculated as the product of W calculated from formula 13.5.2.1 and factor w_k, determined from the following formulae:

– for angles:

$$w_k = 1 + 0.1\,t_k \qquad (13.5.2.5\text{-}1)$$

– in other cases:

$$w_k = 1 + 0.06\,t_k \qquad (13.5.2.5\text{-}2)$$

t_k – corrosion addition, see 2.5 (Part B).

13.5.3 Buckling Strength of Stiffeners

13.5.3.1 The scantlings of cross-section of:

– longitudinal stiffeners of bottom, sides, strength deck and longitudinal bulkheads taking part in the ship longitudinal strength,
– stiffeners and supporting girders of bulkheads and sides,
– pillars,
– cross-ties,
– rows of panting beams fitted at the side stringers level in forepeak and after peak,
– girder webs stiffeners

are to comply with the requirements given in 13.3 for buckling strength, applying the ideal elastic buckling stress σ_E determined below.

The following buckling modes of a stiffener are to be considered:

– lateral buckling of the whole stiffener,
– torsional buckling of the whole stiffener,
– local web buckling,
– flange buckling.

13.5.3.2 For checking the lateral buckling strength of longitudinal stiffeners subjected to compression loads due to hull girder bending, bulkhead supporting stiffeners, pillars, cross-ties, rows of panting beams in the forepeak and longitudinal stiffeners of girder webs, the ideal elastic buckling stress σ_E may be determined from the formula:

$$\sigma_E = 0.001\,E\,\frac{I_\alpha}{A\,l^2}\,,\quad \text{[MPa]} \tag{13.5.3.2}$$

I_α – moment of inertia, without corrosion allowance, about the axis perpendicular to the expected direction of buckling, i.e. perpendicular to the plating, [cm^4];
A – cross-sectional area of stiffener, [cm^2].

When calculating I_α and A, the effective width of plating equal to the stiffener spacing and the thickness equal to t_n may be included – see 13.4.3.4.

The σ_E value, calculated according to formula 13.5.3.2, corresponds to simply supported ends of the stiffener and axial compression.

If, in a particular case, it is verified that one end can be regarded as fixed, the value 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.

The ends of stiffener may be considered fixed if:

– they are connected to the girders having considerable bending stiffness in relation to the supporting member in two perpendicular directions,
– they have end brackets on both ends.

13.5.3.3 At checking the torsional buckling strength of a stiffener, the value σ_E may be determined from the formula:

$$\sigma_E = \frac{\pi^2 E I_w}{10^4 I_0 l^2}\left(m^2 + \frac{K}{m^2}\right) + 0.385E\frac{I_t}{I_0}\,,\quad \text{[MPa]} \tag{13.5.3.3-1}$$

$$K = \frac{c l^4}{\pi^4 E I_w}\cdot 10^6 \tag{13.5.3.3-2}$$

m – number of buckling made half-waves, it may be determined from the following formula:
$(m-1)^2\, m^2 < K \le (m+1)^2\, m^2$, where:
$m = 1$ for $0 < K \le 4$,
$m = 2$ for $4 < K \le 36$,
$m = 3$ for $36 < K \le 144$,
$m = 4$ for $144 < K \le 400$;
I_w – sectorial moment of inertia of the stiffener cross-section about connection of stiffener to plating, [cm^6]:
– for flat bars:

$$I_w = \frac{h_s^3\, t_s^3}{36}\cdot 10^{-6} \tag{13.5.3.3-3}$$

– for T-sections:

$$I_w = \frac{t_m\, b_m^3\, h_s^2}{12}\cdot 10^{-6} \tag{13.5.3.3-4}$$

– for angles and bulb floats:

$$I_w = \frac{b_m^3 h_s^2}{12(b_m + h_s)^2}\left[t_m\left(b_m^2 + 2b_m h_s + 4h_s^2\right) + 3t_s b_m h_s\right] \cdot 10^{-6} \qquad (13.5.3.3\text{-}5)$$

h_s – web height, [mm];

t_s – web thickness, [mm], minus standard deduction according to 13.4.3.4, i.e. assuming $t_s = t_n$;

b_m – flange width, [mm];

t_m – flange thickness, [mm], minus standard deduction according to 13.4.3.4,

For bulb sections, the mean thickness of bulb is to be taken;

l – span of stiffener, [m];

I_0 – polar moment of inertia of stiffener cross-section about connection of stiffener to plating, [cm^4]:

– for flat bars:

$$I_0 = \frac{h_s^3\, t_s}{3} \cdot 10^{-4} \qquad (13.5.3.3\text{-}6)$$

– for stiffeners with flange:

$$I_0 = \left[\frac{h_s^3\, t_s}{3} + h_s^2\, b_m\, t_m\right] \cdot 10^{-4} \qquad (13.5.3.3\text{-}7)$$

I_t – St. Venant's moment of inertia of stiffener cross-section (without effective plate flange), [cm^4]:

– for flat bars:

$$I_t = \frac{h_s\, t_s^3}{3} \cdot 10^{-4} \qquad (13.5.3.3\text{-}8)$$

– for stiffeners with flange:

$$I_t = \frac{1}{3}\left[h_s\, t_s^3 + b_m\, t_m^3\left(1 - 0.63\frac{t_m}{b_m}\right)\right] \cdot 10^{-4} \qquad (13.5.3.3\text{-}9)$$

c – spring stiffness exerted by supporting plate panel:

$$c = \frac{k_p\, E\, t_p^3}{3s\left(1 + \dfrac{1.33\, k_p\, h_s\, t_p^3}{1000\, s\, t_s^3}\right)} \cdot 10^{-3} \qquad (13.5.3.3\text{-}10)$$

k_p = $1 - r$, but not less than $k_p = 0$, (13.5.3.3-11)

$$r = \frac{\sigma_r}{\sigma_{Ep}} \qquad (13.5.3.3\text{-}12)$$

σ_r – design compressive stress, [MPa]; for longitudinal deck beams, bottom and side frames, as well as stiffeners of longitudinal bulkheads – see 13.3.2.7;

σ_{Ep} – ideal elastic buckling stress of supporting plate according to 13.4.3.4;

t_p – plating thickness, [mm], minus standard deduction according to 13.4.3.4.

For stiffeners with flanges, the assumed value of k_p factor need not be taken less than 0.1.

13.5.3.4 For checking the local buckling strength of a web, the value σ_E may be determined from the formula:

$$\sigma_E = 3.8\,E\left(\frac{t_s}{h_s}\right)^2, \quad [\text{MPa}] \tag{13.5.3.4}$$

h_s – see 13.1.2;
t_s – web thickness, [mm], minus standard deduction according to 13.4.3.4.

13.5.3.5 Buckling strength of flange of longitudinal stiffener made of angle or T-section may be considered sufficient if the following requirement is complied with:

$$t_m \geq \frac{1}{15} b_n \tag{13.5.3.5}$$

b_n – flange width for angle bar, half the flange width for T-sections, [mm];
t_m – see 13.5.3.3.

13.5.3.6 For stiffeners supporting plate panels subject to compression perpendicular to the stiffener direction (e.g. transverse deck beams of strength deck, vertical side frames and stiffeners of longitudinal bulkheads), the moment of inertia of stiffener cross-section, including effective plate flange, is not to be less than:

$$I = \frac{0.09\,\sigma_r\,\sigma_E\,l^4 s}{t}, \quad [\text{cm}^4] \tag{13.5.3.6-1}$$

t – plate thickness, [mm];
σ_r – compressive stress, [MPa], acting in plate panels perpendicular to stiffener;

$$\sigma_E = 1.18\,\sigma_r, \quad [\text{MPa}] \quad – \quad \text{when } \sigma_E \leq 0.5\,R_e, \tag{13.5.3.6-2}$$

$$\sigma_E = \frac{R_e^2}{4\left(R_e - 1.18\,\sigma_r\right)}, \quad [\text{MPa}] \quad – \quad \text{in other cases;} \tag{13.5.3.6-3}$$

l, s – see 13.1.2.

13.6 Simple Girders

13.6.1 General Requirements

The structure of simple girders and the scantlings of their structural parts are to comply with the below specified requirements within the scope of:

– minimum thickness, as given in 13.2,
– section modulus, as given in 13.6.2,
– web cross-sectional area, as given in 13.6.3,
– buckling strength, as given in 13.6.4.

13.6.2 Section Modulus

13.6.2.1 The section modulus of a girder, subjected to lateral load, is to be calculated including effective plate flange, determined according to 3.2.2, about the neutral axis parallel to the plating. The net section modulus, i.e. after deduction of corrosion additions according to 2.5, if required, is not to be less than that determined from the formula:

$$W \geq \frac{1000 l^2 b p}{m \sigma}, \quad [\text{cm}^3] \qquad (13.6.2.1\text{-}1)$$

l, b, p – see 13.1.2;

σ – allowable stress determined as follows:

– for the continuous longitudinal girders amidships:

$$\sigma = 190k - 130 f \frac{z_n - z_a}{z_n}, \quad [\text{MPa}] \qquad (13.6.2.1\text{-}2)$$

but not more than 160 k [MPa];

– for the longitudinal girders in peaks:

$$\sigma = 160k, \quad [\text{MPa}]$$

The value of σ varies linearly between the above specified regions;

– for transverse and vertical girders:

$$\sigma = 160k, \quad [\text{MPa}]$$

m – bending moment factor (see 5.2.3.3), in general m = 10 may be taken.

13.6.2.2 Design values of W may be determined according to the requirements of 13.5.2.5.

13.6.3 Web Cross-section Area

13.6.3.1 Effective web cross-section area of girder subjected to the lateral load, determined according to 3.2.3, is not to be less than:

$$A = \frac{c k_1 l b p}{k} + 0.01 h_s t_k, \quad [\text{cm}^2] \qquad (13.6.3.1)$$

c = 0.75 – for web of watertight bulkhead girders (not applicable to the collision bulkhead),

c = 1.0 in other cases;

k_1 = 0.06 – for continuous horizontal girders, as well as upper ends of vertical girders of sides and bulkheads,

k_1 = 0.08 – for lower ends of vertical girders of sides and bulkheads,

k_1 = 0.07 – for deck girders;

l, b, p, h_s, t_k – see 13.1.2.

13.6.3.2 The web cross-section area in the middle of the span is not to be less than half the value determined from formula 13.6.3.1.

13.6.4 Buckling Strength of Girders

13.6.4.1 The buckling strength of girders subjected to axial loads (pillars and cross-ties) is to be checked in compliance with 13.7.3 and 13.7.4.

13.6.4.2 The buckling strength of girders subjected to transverse loads and possible additional axial loads due to the hull girder bending is to comply with the following requirements:
– lateral buckling strength of the whole girder need not, in general, be checked;
– it is assumed that the requirements regarding torsional buckling of girders and local buckling of flanges are complied with, if requirements of 3.6.2 and 3.6.4 are satisfied;
– girder webs are to comply with local buckling strength criteria, given in 13.3.2.2, 13.3.2.3 or 13.3.2.5 for design stress value determined according to 13.3.2.7 or 13.3.2.10. Their stiffening or strengthening in accordance with the requirements of 3.6.3 may be required for that purpose.

13.6.4.3 For girders supporting longitudinal stiffeners (deck beams, frames, longitudinal bulkhead stiffeners) or girders supporting other stiffeners subjected to axial compression stresses, the moment of inertia of girder cross-section (including effective plate flange) is not to be less than:

$$I = 0.3\frac{l_w^4\,I_u}{b^3\,s}, \quad [\text{cm}^4] \qquad (13.6.4.3\text{-}1)$$

l_w – span of the girder, [m];
b – distance between girders, [m];
s – spacing of stiffeners, [m];
I_u = $\dfrac{\sigma_E A l^2}{0.001 E}$, [cm^4] – moment of inertia of compressed stiffener cross-section, necessary to satisfy the requirements of 13.5.3.2;

$$\sigma_E = 1.18\,\sigma_r \text{ if } \sigma_r \le 0.5\,R_e, \qquad (13.6.4.3\text{-}2)$$

$$\sigma_E = \frac{R_e^2}{4\left(R_e - 1.18\,\sigma_r\right)}, \text{ [MPa] – in other cases;} \qquad (13.6.4.3\text{-}3)$$

σ_r – the compressive stress in the stiffener, [MPa];
A – cross-section area of stiffener, as given in 13.5.3.2, [cm^2];
l – span of stiffener, [m].

13.7 Pillars and Supporting Members

13.7.1 Application

The requirements of the present sub-chapter apply to members subjected to compressive axial stresses: deck pillars, vertical stiffeners and bulkhead girders supporting deck structures, panting beams in peaks and cross-ties in tanks.

13.7.2 General Requirements

13.7.2.1 As far as practicable, the deck pillars are to be fitted in line with the upper and lower pillars.

13.7.2.2 Transverse web beams in decks and platforms of machinery spaces are to be fitted in line with side web frames and deck pillars to form stiff frame structures.

13.7.3 Pillars and Supporting Stiffeners

13.7.3.1 The critical buckling stress σ_c of pillars, cross-ties and panting beams, determined according to 13.5.3 and 13.3.2.2, is to be not less than:

$$\sigma = \frac{10P}{Ak_1}, \quad \text{[MPa]} \qquad (13.7.3.1\text{-}1)$$

P – axial load, as given in 13.7.3.2, 13.7.4 or obtained from direct stress analysis according to Chapter 14, [kN];

$$k_1 = \frac{k_2}{1+\frac{l}{i}}, \text{ but not less than 0.3;} \qquad (13.7.3.1\text{-}2)$$

k_2 = 0.5 – for supporting members of weather deck within $x \geq 0.4\ L_0$, as well as for cross-ties and panting beams in side tanks and peaks,
k_2 = 0.6 – for supporting members of weather deck when sea loads are applied,
k_2 = 0.7 – in other cases;
$i = \sqrt{\frac{I_\alpha}{A}}$ – radius of gyration of cross-section of the supporting member, [cm];
I_α, A – see 13.5.3.2;
l – span of a pillar, cross-tie or panting beam.

13.7.3.2 The nominal axial force in deck pillars is to be determined from the formula:

$$P = \sum P_i, \quad \text{[kN]} \qquad (13.7.3.2)$$

P_i – force transmitted to the considered pillar from deck i, [kN].

The force transmitted from deck girders is to be taken equal to half the sum of lateral forces acting on girders supported by the considered pillar.

13.7.4 Cross-ties and Panting Beams

The required cross-sectional area of cross-ties in tanks and panting beams in peaks is to be determined according to 13.7.3.1, taking k_2 = 0.5 and the axial force determined from the formula:

$$P = l\,b\,p, \quad \text{[kN]} \qquad (13.7.4)$$

l – mean span of a girder or frame supported by a cross-tie or panting beam, [m];
b – plating breadth supported by a girder or frame as given in 3.2.2.3, [m].

13.8 Brackets

13.8.1 Application

The requirements of the present sub-chapter apply to brackets connecting stiffener and girder ends to other structures.

13.8.2 End Connections of Stiffeners

13.8.2.1 All types of stiffeners are to be connected at their ends with brackets. In special cases, bracketless connections or snipped ends of stiffeners may be allowed.

13.8.2.2 The scantlings of end brackets of stiffeners taking part in longitudinal strength of ship are to be determined taking into account forces acting in the stiffener considered and using the allowable stresses equal to those taken for stiffeners.

13.8.2.3 The scantlings of brackets for stiffeners not taking part in the longitudinal strength are to comply with requirements of 13.8.2.4 to 13.8.2.8 (see also Fig. 13.8.2.3 and 3.2.1.1).

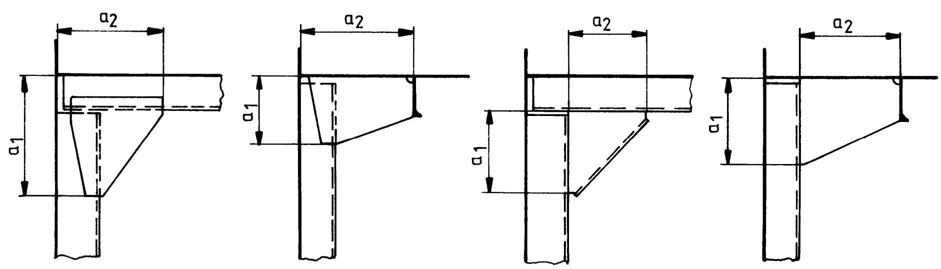


Fig. 13.8.2.3 Stiffener end brackets

13.8.2.4 The thickness of bracket t_w is to be determined from the formula:

$$t_w = \frac{3 + k_1\sqrt{W}}{\sqrt{\frac{k_w}{k_u}}} + t_k, \quad \text{[mm]} \qquad (13.8.2.4)$$

W – rule section modulus for the stiffener (the minimum value if more than one stiffener have been attached to the bracket), [cm^3];
k_1 – 0.2 for flanged brackets along free edge,
k_1 – 0.3 for unflanged brackets;

k_w – material factor for bracket (see k in 2.2.1.2);
k_u – material factor for stiffener.

The bracket thickness t_w is not to be less than 6 mm and need not be greater than 13.5 mm; the corrosion addition t_k need not exceed 1.5 mm.

13.8.2.5 The bracket arm length a is to be determined from the formula:

$$a = c\sqrt{\frac{W}{t_w}}\,, \quad \text{[mm]} \qquad (13.8.2.5\text{-}1)$$

W, t_w – according to 13.8.2.4;
a – see Fig. 13.8.2.3;
c = 70 for flanged brackets along free edge,
c = 75 for unflanged brackets.

The arm length a is not to be less than 2 times the depth of the stiffener web. In the case of different arm lengths a_1 and a_2, their sum is not to be less than 2 a and the length of the smaller arm is not to be less than 0.75 a (see Fig. 13.8.2.3). Where the length of free edge exceeds 50 t_w, a flange or edge stiffener is to be fitted, its width being taken not less than that calculated from the formula:

$$b = 40\left(1 + \frac{W}{1000}\right), \quad \text{[mm]} \qquad (13.8.2.5\text{-}2)$$

but not less than 50 mm.

13.8.2.6 The bracket scantlings are to be such that the section modulus of the connection cross-section in way of bracket is not less than that required for the stiffener.

13.8.2.7 Bracketless end connections may be applied for longitudinals and other stiffeners running continuously through girders (web frames, web deck beams, bulkheads), provided sufficient welded joints are arranged (for longitudinals see also 6.2.2.2 and 8.2.2).

13.8.2.8 Stiffeners with snipped ends may be allowed where dynamic loads are small and where vibrations are to be considered to be of small importance, provided the thickness of plating supported by the stiffeners is not less than calculated from the formula:

$$t = 1.25\sqrt{\frac{(l - 0.5\,s)\,s\,p}{k}} + t_k\,, \quad \text{[mm]} \qquad (13.8.2.8)$$

l – stiffener span [m];
s – stiffener spacing, [m];
p – pressure acting on plating supported by stiffener in question, [kPa].

13.8.3 End Connections of Girders

13.8.3.1 Ends of girders or connections between girders forming frame systems are to be provided with brackets.

The free edges of the brackets are to be rounded with a radius or well rounded at their toes and stiffered.

Bracketless connections may be applied, provided adequate support of adjoining face plates is arranged.

13.8.3.2 The thickness of girder brackets is not to be less than that of the girder web plate.

Girder brackets are to have along their free edges the face plates with cross-sectional area not less than:

$$A_{mw} = 10\, l_w\, t_w\,, \quad [\text{cm}^2] \qquad (13.8.3.2)$$

l_w – length of free edge of bracket, [m];
If l_w exceeds 1.5 m, the bracket is to be fitted with an additional stiffener parallel to the face plate and maximum 0.15 m from the edge, the cross-sectional area of the face plate being equal to 60% of the value determined from the above formula and the cross-sectional area of the stiffener equal to 40% of this value;

t_w – thickness of bracket, [mm].

Where face plate of the girder is continuous with the bracket face plate, as far as possible, the change in face plate dimensions is to be gradual. Where there is a discontinuity between the face plates, the face plate of the girder is to extend well beyond the toe of the bracket.

13.8.3.3 The bracket arm length, including the girder depth is to be determined from the formula:

$$a_w = c\sqrt{\frac{W}{t_w}}\,, \quad [\text{mm}] \qquad (13.8.3.3)$$

W – the required section modulus of the girder connected with the bracket, [cm^3];
t_w – bracket thickness, [mm];
c = 63 for bracket of bottom and deck girders,
c = 88 in other cases.

Other values of c may be accepted after special consideration by PRS.

13.8.3.4 Normal stresses in mid length of bracket free edge are not to exceed the allowable stresses specified in 14.4 increased by:

- 25% for structures where the bracket with stiffened edge is welded to the face plates of connected girders,
- 45% for structures where the bracket is an integral part of both girders, its face plate being an extension of the girder face plates.

13.8.3.5 At cross joints of bracketless connections, the required flange area of face plate may be gradually tapered beyond the crossing flange. For flanges in tension, the allowable tensile stress is to be reduced when lamellar tearing of flanges may occur.

The thickness of girder web at cross joints of bracketless connection (see Fig. 13.8.3.5) is not to be less than the greater value determined from the following formulae:

$$t_3 = \frac{\sigma_1}{k_t}\frac{A_1}{h_2} - \frac{\tau_2}{k_t}\frac{t_2}{100}, \quad \text{[mm]} \qquad (13.8.3.5\text{-}1)$$

$$t_3 = \frac{\sigma_2}{k_t}\frac{A_2}{h_1} - \frac{\tau_1}{k_t}\frac{t_1}{100}, \quad \text{[mm]} \qquad (13.8.3.5\text{-}2)$$

A_1, A_2 – minimum required flange cross-sectional area of girder 1 and 2, respectively, [cm^2];
h_1, h_2 – height of girders 1 and 2, [mm];
t_1, t_2 – minimum required thicknesses (outside region 3) of girder 1 and 2 web plates, [mm];
σ_1, σ_2 – bending stresses in girders 1 and 2, [MPa];
τ_1, τ_2 – shear stresses in webs of girders 1 and 2, [MPa];
k_t – material factor for corner web plate (region 3) of the web.

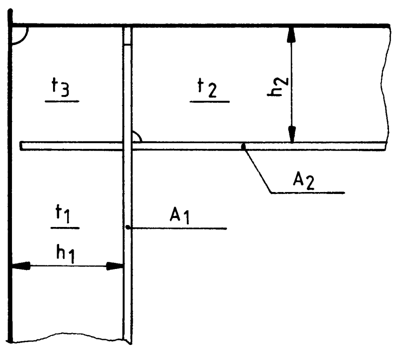


Fig. 13.8.3.5 Bracketless connection of girders

14 PRINCIPLES OF FINITE ELEMENTS METHOD CALCULATIONS – ZONE, GENERAL AND LOCAL STRENGTH

14.1 General

14.1.1 Application

14.1.1.1 The requirements of the present Chapter are applicable for:
- ship's hull girder system strength analysis;
- hull general strength analysis in cases, when the strength assessment in accordance with the requirements of Chapter 15 (e.g. in ships with superstructures located amidship, ships with wide openings in decks, etc.) cannot be performed;
- hull's stiffeners strength assessment in cases, when methods and criterion given in 13.5 cannot be applied.

Determined values of stresses may be applied in the shell, girders webs and stiffeners stability analysis – in accordance with criterion given in 13.3.2 i 13.4.3.

14.2 Design loads

14.2.1 Stresses analysis in the structure shall be performed for the most unfavourable, actual load conditions of the ship.

Following conditions shall be taken into account:
- the ship in full displacement condition;
- the ship in the maximum displacement condition (if in the ship's design the assumption is made, that the draught is more than *T*), and with lower displacements, applicable in service (e.g. with incomplete mass of stocks or water ballast);
- handling the ship in stay or in motion, as well as supplying the ship in motion.

For ships in at sea conditions, a real combination of internal and external dynamic loads, as defined in 17.5, shall be incorporated. In port conditions (transhipment operations) dynamic loads can be omitted. Loads from the forces of gravity and inertia of deck construction elements may be omitted if they are less than 5% of the computational loads. Method of application of load to strength structure models is defined in 14.3.3, 14.4.3 and 14.6.

14.3 Assessment of the Zone Strength on the Basis of Beam FEM Models

14.3.1 Application

14.3.1.1 The term „beam FEM model" means models in a form of continuous beams, flat frames and three-dimensional frames.

Such models may be accepted in case of zone strength analysis of the hull structure modulus consisting of flat, or almost flat, stiffened fragments of the plating, strengthened with girders (such as side shell, bottom, decks bulkheads), which can be considered as slender.

14.3.1.2 The zone strength analysis of the structure with strongly variable shapes (such as the hulls without middle body or end parts of the hulls) shall be made in accordance with the requirements of sub-chapter 14.4.

14.3.2 Principles of Structure Modelling

14.3.2.1 FEM model beam elements shall, in general, be located in a neutral axis of the section under consideration.

In the case of T beams welded to the shell plating, placing of elements in a line of the web contact with plating is permissible.

14.3.2.2 FEM calculations with application of beam elements shall be made in a linear-elastic range, with consideration of deformations due to bending, shear, torsion, tension and compression.

14.3.2.3 Strength characteristics of the model elements' transverse sections (section area, moment of inertia and section moduli) shall be determined for net thicknesses of structural elements, e.g. after deduction of corrosion allowances according to 2.5.

14.3.2.4 Moments of inertia and section moduli of the girders shall be calculated for the web with the effective flange or flanges (in the case of double skin structures).

Width of effective flange shall be determined in accordance with 3.2.2.1. Stiffeners located on the effective flange may be considered in accordance with the requirements of 3.2.2.1.

The webs of T girders shall be considered in its entirety.

14.3.2.5 In the area of openings in a web, shear area shall be taken as an effective web section area determined in accordance with 3.2.3.

14.3.2.6 Torsional constant for the T girders (Fig. 14.3.2.6a) shall be determined from the formula:

$$I_0 = \frac{1}{3}\sum_{i=1}^{3} l_i t_i^3 \, . \qquad (14.3.2.6\text{-}1)$$

Torsional constant for the girders in double skin structures shall be determined from the formula:

$$I_0 = \frac{b_m \cdot h_s^2}{\dfrac{1}{t_1} + \dfrac{1}{t_2}} \, . \qquad (14.3.2.6\text{-}2)$$

Thicknesses t_1 and t_2 in the above formulae are the net thicknesses of the plating.

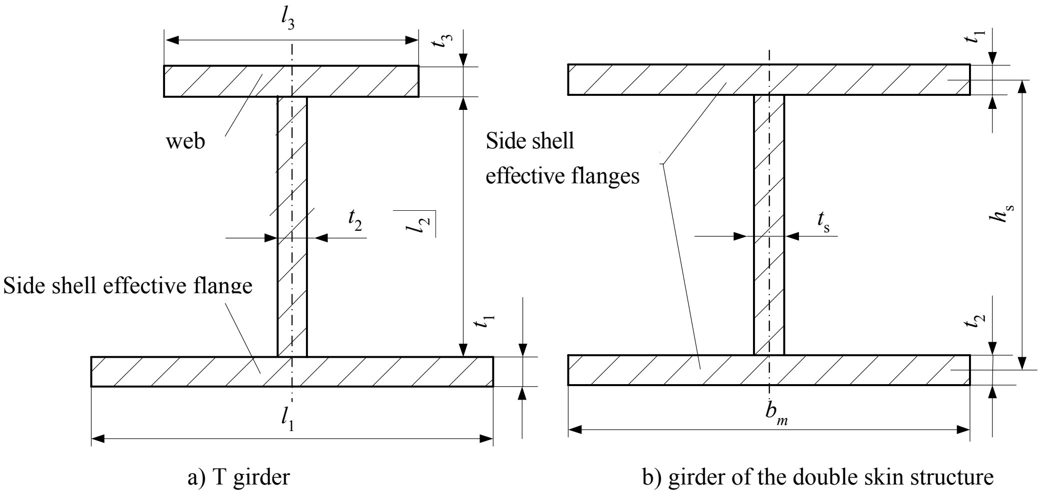


Fig. 14.3.2.6

14.3.2.7 In areas of brackets and girders crossing rigid beam elements (or rigid ends of elements – if computer software allows) with lengths determined acc. to Fig. 14.3.2.7, shall be applied.

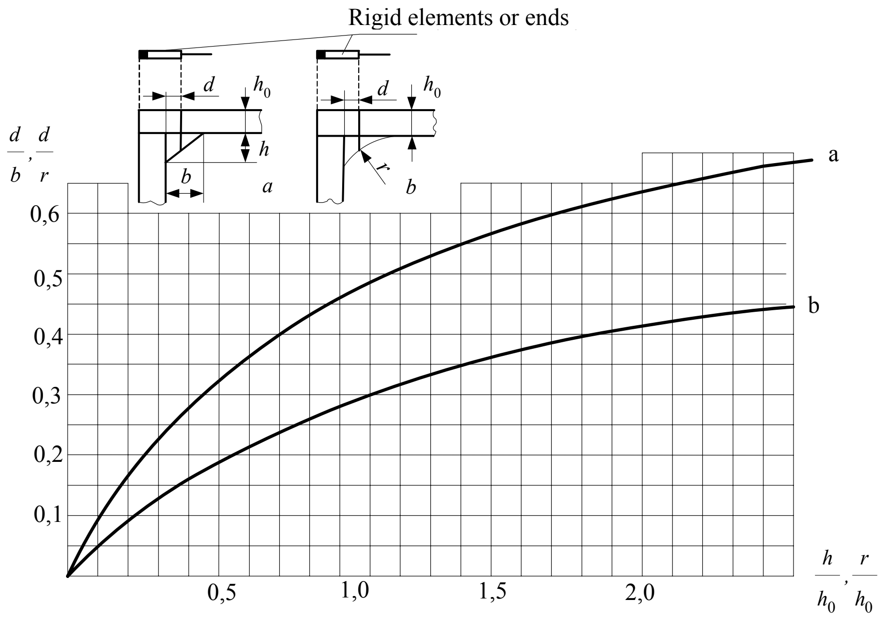


Fig. 14.3.2.7 Determination of rigid elements or rigid ends length

Strength characteristics of the rigid elements shall be determined in the following way:

– moment of inertia shall be assumed 100 times of the average elements with finite rigidity, applied in given model, moment of inertia,

– section area and shear section area shall be assumed 10 times of the average elements with finite rigidity, applied in given model, relevant sections' area.

14.3.3 FEM Model Loads

14.3.3.1 Loads of FEM model due to water pressure, liquid stores or stores loads on decks shall be imposed to the beam elements in a form of continuous load of value:

$$q = p \cdot b \tag{14.3.3.1}$$

where:

p – calculation pressure,

b – width of supported plating strake (equal to a half of distance between adjacent girders, bulkheads, etc).

14.3.3.2 Load from the equipment, containers, etc., may in general be imposed in a form of point loads to FEM model joints.

14.3.3.3 At the edge of FEM model, loads in the form of concentrated forces and moments resulting from loads acting on the hull structure outside the region, which is covered by a FEM model, shall be applied.

14.3.4 Boundary Conditions

14.3.4.1 Nodes of FEM model may, generally, be supported non-displaceably in a vertical direction, in the planes of sides, transverse and longitudinal bulkheads, as well as vertical divisions.

14.3.4.2 At the edge of FEM model, interaction of analyzed fragment of the structure with the rest of the hull – in the form of the respective springs connected to the nodes of the model, shall be considered.

14.3.4.3 FEM model may embrace the hull structure fragments on one side of the plane of symmetry. In such case, under symmetrical load, adequate boundary conditions in the plane of symmetry (nought rotation angle of the nods around longitudinal and vertical axis) shall be applied.

14.3.5 Permissible Stresses

Permissible values of stresses in girders, relevant to calculation loads according to Chapter 17, are given in 14.5.

14.3.6 FEM Calculations Report

14.3.6.1 Calculations Data

Report on calculations shall include following information concerning applied input data:

– arrangement of beam elements (drawing of the model – generated e.g. by the computer programme – and co-ordinates of the nodes);

- assumed for calculations sections of beam elements and values of their strength characteristics (strength and section moduli, etc.);
- applied loads;
- applied boundary conditions;
- material properties (Young's modulus, Poisson's coefficient, yield point).

14.3.6.2 Calculations Results

Presented calculations results shall include:

- the drawing of deformed structure (computer print) and the maximum values of the nodes shift;
- the values of stresses in individual FEM model elements.

14.4 Assessment of the Zone Strength on the Basis of FEM Models with Application of Membrane, Shell and Beam Finite Elements

14.4.1 Application

14.4.1.1 Requirements of the sub-chapter 14 apply to calculations of the zone strength with application of spherical FEM models (application of membrane, shell and beam finite elements).

14.4.1.2 FEM model should comprise adequately large module of the hull construction, so that in the area, where the strength of the girders is assessed, the influence (on the results of the calculations) of inaccurate modelling of interaction FEA model girders with the other girders be minimized – in the form of boundary conditions posed on the model edge.

The minimum required range of FEM model includes a module of the hull from the middle of the space between watertight bulkheads, to the centre of such adjacent space. However, it is advisable to develop a FEM model which includes three consecutive spaces between watertight bulkheads.

14.4.1.3 Where the boundary conditions, in a form of designated values of relocations, are assumed on the basis of the results of FEM hull general strength analysis in accordance with 14.6, model FEM may be less extended.

14.4.1.4 The calculation results of FEM model required in 14.4.1.2, may be utilized as the boundary conditions for the local FEM strength analysis, in accordance with 14.7.

14.4.2 Principles of the Structure Geometry Modelling

14.4.2.1 Following principles of modelling relate to FEM calculations in a linear-elastic range, with application of models, where 4-nodal membrane or shell finite elements and 2-nodal rod or beam elements are applied .

Application of higher order elements (8-nodal or 6-nodal) generally enables use of a more coarse division into finite elements, than is required below. Such models are subject to separate consideration by PRS.

Application of 3-nodal elements should be avoided. To avoid unacceptable shapes of quadrangle elements – in exceptional cases 3-nodal elements may be applied.

14.4.2.2 FEM model should take into account all the girders in the analysed hull module (with brackets), plating and plating stiffeners.

Net thickness of structural elements should be applied, i.e., corrosion allowances required in 2.5 shall be deducted.

In the case of curved webs of girders or curved plating (e.g. at bilge), and for obtaining value of effective area A_e acc. to 3.2.2.4 and 3.2.2.5, their reduced effectiveness in bending condition shall be regarded by application of reduced plate thickness.

14.4.2.3 Plating stiffeners in a form of 2-node beam non-axial elements, e.g. those taking account to the shift of stiffener neutral axis in relation to the plating, shall be considered.

In the case that in actual computer programme application of such elements is not possible, stiffeners' modelling in a form of 2-node rod elements in a plane of plating, is permissible. Relevant section areas of these elements shall, however, be reduced in relation to section areas of stiffeners, for proper representation of girder's bending stiffeness with stiffened belts of plating.

14.4.2.4 Girders' face plates and stiffeners applied for ensuring girders' webs stability may be considered in a form of rod 2-node elements. In the case of curved face plates, requirements of 14.4.2.2 shall apply.

14.4.2.5 For FEM modelling of plating, girders' webs and brackets with application of membrane or shell elements, following principles shall be observed:
- ratio of the longer quadrangle element's side length to the shorter side length should not, in general, exceed 2, and in no case shall be greater than 4;
- an angle between element sides shall be in a range 60° do 120°;
- angles of triangle elements (if their application cannot be avoided) shall be in a range 30° do 120°.

14.4.2.6 For modelling of plating, division to finite elements shall be such, that their size is not greater than given in following minimum requirements:
- at the height of girders webs at least 3 finite elements shall be applied, and the web division to elements shall be adjusted to web's stiffeners arrangement;
- at dividing to finite elements of hull shell plating, plating of decks and bulkheads, at least one finite element between neighbouring stiffeners shall be applied; in the direction along the ship, the length of finite elements sides shall not be greater than frame spacing.

14.4.2.7 Small openings and cuts in girders webs (overflow and air openings, cuts for the passage of plating stiffeners) may be disregarded in FEM model.

Communication and lightening holes may, in general, be taken into account by application in area of these openings, on entire height of the web, elements of reduced thickness (proportionally to the opening height) in such manner, that the actual value of the web sheer transverse section is maintained.

In the case, where the openings of non-typical dimensional proportions, or openings of relatively big dimensions are applied, their direct consideration in the FEM model may be required.

14.4.2.8 The web brackets shall be directly considered in the FEM model. Sides of finite elements in region of such brackets shall not be greater than 250 mm, while in each case, along the free edge of the bracket side of at least 3 finite elements shall be placed.

14.4.3 Load

14.4.3.1 If the plates of plating are modelled by shell elements, and the stiffeners are modelled by beam elements, then load from outside the hull water, and loads from ballast water or liquid stores from inside the hull may be imposed to FEM model in a form of pressures.

14.4.3.2 If the plates of plating are modelled by membrane elements, than the loads described in 14.4.3.1 shall be applied in a form of continuous loads in planes of stiffeners' webs (in situation when the girders webs are modelled by membrane elements) or in planes of the girders.

The value of the continuous load is equal to the value of the pressure multiplied by the width of supported plating strake.

14.4.3.3 Loads from the equipment elements and the armament of the ship, as well as the stores other than liquids in integral hull tanks, shall be applied in a form of continuous loads, in accordance with principles of 14.4.3.2.

It is recommended that the loads, close to concentrated loads, are also applied in a form of a continuous load – at the relatively short distance.

14.4.4 Boundary Conditions

14.4.4.1 For the loads symmetric in relation to the hull plane of symmetry (PS) the FEM model covering module of structure between PS and the ship side may be applied.

In such case in PS, boundary conditions relevant to the symmetry shall be applied, e.g.:

– zero values of nodes shift in a direction perpendicular to PS;
– zero values of bracket rotation angles around longitudinal and vertical axis.

14.4.4.2 In the case of FEM models of the hull structure modulus with range required in 14.4.1.2, in the nodes situated in the end frame sections, symmetry conditions in a form of zero values of rotation angles around transverse and vertical axis, and zero values of longitudinal shift, may, in general, be applied.

If the FEM model is simultaneously utilized to assessment of the hull general strength, then in the above planes boundary conditions specified in 14.6.3.4 shall be applied.

14.4.4.3 Nodes of FEM model in planes of sides and bulkheads may, in general, be supported in the vertical direction, at the level of the uppermost deck.

14.4.5 Report of FEM Calculations

14.4.5.1 Calculations Data

Report on calculations shall include complete information concerning applied input data.

In each case the following information shall be given:

- assumed plates thicknesses (in a form of FEM model colour map, or numerical values on the FEM model background);
- transverse sections of the webs modelled by the rod elements;
- effective cross section areas of the curved webs or the substitute thickness of the curved plating;
- parameters of the transverse sections of the beam elements;
- applied boundary conditions (description or in graphical form – on the FEM model drawings);
- applied loads (form as above);
- material properties (Young's modulus, Poisson's coefficient, yield point).

14.4.5.2 Calculations Results

Report on obtained calculation results shall include:

- the drawing of deformed structure with information on the maximum values of the nodes shift;
- the values of the normal, sheer and reduced stresses in individual FEM model membrane or shell elements – in a form of colour map, or numerical values on the FEM model background.

14.5 Girders Permissible Stresses

14.5.1 Application

Values of permissible stresses given in the present sub-chapter are applicable to the calculations in accordance with the requirements of 14.3 i 14.4.

In the case of calculations acc. to 14.4, requirements of the sub-chapter 14.5.2, relating to interpretation of calculated stresses, shall also be taken into account.

14.5.2 Interpretation of the Stresses Calculated with Application of Membrane or Shell FEM Models

14.5.2.1 Normal stresses σ , subject to assessment, are membrane stresses. In the case of shell elements, these are internal plane stresses (stresses in the midlle of the plates thickness).

14.5.2.2 Sheer stresses τ in the girders webs subject to assessment, are mean stresses, calculated for the effective section area of the web with openings acc. to 3.2.3.

14.5.2.3 Reduced stresses shall be calculated from the formula:

$$\sigma_{zr} = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3\tau^2}\ , \quad \text{[MPa]} \qquad (14.5.2.3)$$

where:
x, y – axis of local co-ordinate system;
σ_x – normal stresses in x axis direction;
σ_y – normal stresses in y axis direction;
τ – sheer stresses in xy plane.

14.5.2.4 In the case where finite elements of constant stresses values in the extent of the element are applied, consideration of the actual stresses variation in the extent of element may be required.

In such situations, assuming that the computer programme calculates values of stresses in the middle of the element, linear interpolation may be applied.

14.5.2.5 Values of stresses in regions of notches may, in general, be greater than permissible stresses defined in 14.5.3.

Values of such stresses are subject of separate PRS consideration.

In such cases analysis of fatigue strength in the region of notches – in accordance with the Chapter 16, may be required.

14.5.3 Values of Permissible Stresses

14.5.3.1 For girders, which do not transfer stresses from general bending or the hull torsion (such, as transverse, vertical girders, etc.) values of the permissible stresses are as follows:
$\sigma = 160k$, [MPa] (in the direction of the web axis);
$\tau = 90k$, [MPa], for the girders with one effective flange;
$\tau = 100k$, [MPa], for the girders with two effective flanges;
$\sigma_{zr} = 180k$, [MPa].

14.5.3.2 For the girders transferring normal stresses from the general bending or torsion (longitudinal girders), values of the permissible stresses are as follows:
- acc. to 14.5.3.1, where the stresses from general bending or the hull torsion are not considered;

– σ = 190*k*, [MPa] – permissible value of the aggregate normal stresses in girders, from the zone bending and from general bending or torsion; for calculations 0.59 value of M_w determined acc. to 15.5 (see 15.1.1.2) or 0.59 value of bending and torsional moments acc. 15.12.3 i 15.13.3 and 0.35 value of M_w as above (as in formula 15.3.4.1-1).

14.5.3.3 Permissible value of normal stresses in the middle of the free edge of the girder's bracket, along the bracket end, is 200*k,* [MPa].

Above requirement applies to all girders. In the case of longitudinal girders, both load variants, required in 14.5.3.2, shall be considered.

14.5.3.4 Values of the permissible stresses given in 14.5.3.1÷14.5.3.3 concern loads in sea conditions, determined acc. to Chapter 17.

For the port conditions (loading operations), and for the ship-in-repair conditions, the values of permissible stresses may be increased by 10% to the given above.

14.6 Assessment of General Strength with FEM Application

14.6.1 Application

14.6.1.1 In situations where calculations of Chapter 15, based on beam or rod hull model, can not be applied for the assessment of the general strength of the hull, FEM calculations, applying membrane – rod or shell – rod model, in accordance with the requirements of subdivision 14.6, shall be performed.

Such calculations are required, e.g. in the case of the hulls without midship body, ships with long superstructures in the central part, the hulls with wide hatch openings.

Calculations by this model can also be used to determine the boundary conditions for the analysis of the zone strength.

14.6.1.2 Assessment of the general hull strength may be performed with application of FEM model in accordance with the requirements of 14.4.1.2, applied for the zone strength analysis.

14.6.2 Requirements for FEM Models

14.6.2.1 Assessment of the hull general strength shall be performed for the gross scantlings of the structure's elements, e.g. without deduction of corrosion allowances.

14.6.2.2 FEM model shall include modulus in the middle part of the ship's hull, with a range required in 14.4.1.2, or entire hull of the ship.

14.6.2.3 FEM model should precisely enough represent rigidity of the structure.

Minimum requirements concerning division of the structure in finite elements are following:

- longitudinal stiffeners of the side plating, decks and bulkheads plating, etc., may be modelled in a form of rods located in planes of stiffened by them plates, and grouped by several pieces;
- girders' webs may be divided into finite elements in such a way, that at the height of the web there is only one finite element;
- girders' face plates may be modelled by rod elements;
- side plating may, in general, be divided into finite elements in such a way, that there is only one row of finite elements between neighbouring girders;
- cuts in girders, through which plating stiffenings pass, and other small cut-outs and holes can be neglected in division of the structures into the finite elements;
- communication holes in the girders shall be considered; in regions, where such openings are located, application substitute thicknesses in FEM model is permitted, provided that the value of cross section of the web with hole is preserved.

Note: in the case of structure considered by PRS as non-typical, application of more precise FEM model may be required.

14.6.2.4 Membrane or shell finite elements shall comply with the requirements of 14.4.2.5.

14.6.3 Loads and Boundary Conditions

14.6.3.1 Loads shall be applied to the FEM model in the most realistic mode, i.e. in the form of water pressure from the outside, the pressure of liquid stocks, and the pressures on the foundations from the elements of equipment.

14.6.3.2 After consultation with PRS, in the case of analysis of general bending or torsion of the hull, resultant load in particular frame sections may be imposed to the sides and bulkheads in a form of continuous load (along the ship).

14.6.3.3 As far as practicable, application of pillars in the terminal transverse sections of FEM model (at the end of the hull module) – in order to balance the internal forces in these sections of the hull, shall be avoided.

Self-balanced loads shall be applied to the FEM model. So loaded model shall be supported by springs in vertical, transverse and longitudinal direction (by applying possibly minimum number of the springs) in order to eliminate unavoidable existing lack of balance (mistakes in rounded off results)

The springs shall be placed in nodes laying on the intersections of the side shell or longitudinal bulkheads with the transverse bulkheads.

14.6.3.4 When applying FEM model of the hull module, normal and tangential stresses corresponding to bending moments and forces shearing the hull, shall be applied in the end cross-sections, in a manner resulting from the theory of thin-walled beams bending.

Application of constraints, forcing the flatness of the final sections of the module (FEM model), and imposing there bending moments in the form of pairs of forces (concentrated forces imposed to the model nodes in PS), is permitted.

14.6.3.5 In the case of symmetrical hulls, application of FEM model including the hull structure on one side of plane of symmetry, is permitted. \.

In the case of general bending analysis, boundary conditions defined in 14.4.4.1 shall be applied in the vertical plane.

14.6.4 Permissible Stresses

14.6.4.1 Values of permissible stresses are given in 15.2.1 i 15.12.2 (σ for general bending in vertical plane and simultaneous bending in vertical and horizontal plane) and in 15.11 (τ for bending in vertical plane).

14.6.4.2 In the places of the stresses concentration, values of the stresses calculated by the computer programme may, in general, exceed values determined in 14.6.4.1.

Such situations are subject of separate PRS consideration in each particular case.

14.6.5 Report on FEM Calculations

14.6.5.1 Report on FEM calculation, in a scope identical to that determined in 14.4.5. is required.

14.7 Assessment of the Local Strength on the Basis of Membrane, Shell and Rod Finite Elements

14.7.1 Application

For the strength assessment of the being bent plating stiffeners and their brackets – especially in situations, where the stresses values in the stiffeners are significantly affected by deflection of girders supporting stiffeners, calculations of local strength with application of specially developed FEM models, may be required.

Such calculations may also be required for checking the strength of machinery, equipment and armament foundations, as well as the hull structure in areas of various cuttings, communication holes in plating, etc.

14.7.2 Requirements for FEM Models

14.7.2.1 Division into finite elements shall comply with the following requirements:

– at the height of stiffener web, at least 3 membrane or shell elements shall be applied;
– face plates of symmetrical stiffeners may be modelled with application of 2-node rod elements;

– face plates of non-symmetrical stiffeners and their brackets shall be modelled with application of membrane or shell elements with size close to the size of elements applied in region of webs;
– when modelling plating with openings (e.g. communication) length of finite elements sides in direct vicinity of the opening shall not be greater that 200 mm;
– shape and dimensional proportions of the finite elements sides shall comply with the requirements of 14.4.2.5;
– rapid change of finite elements sides' dimensions in, so called, transition zones – from elements of relatively small dimensions to elements of much bigger size, shall be avoided.

14.7.3 Assessment of the Stiffeners Strength with Application of FEM model to Zone Strength Calculations

14.7.3.1 In order to assess the level of aggregated normal stresses in the plating stiffeners from bending of girders and local bending of stiffeners, FEM model in the region of stiffener shall meet the requirements of sub-chapter 14.7.2.

Otherwise, a separate calculations of stresses from the local bending, which should be added to the stresses from the girders bending, shall be performed. For the stiffeners locally bent, a model of the bent beam may, in general, be applied.

14.7.4 Load and Boundary Conditions

14.7.4.1 For loads modelling, principles determined in 14.4.3 shall be applied.

14.7.4.2 Boundary conditions shall be determined in the form of shifts' assigned values on the edge of the model, which result from FEM analysis of the zone strength – acc. 14.4.

14.7.5 Permissible stresses

14.7.5.1 Levels of the stresses determined in effect of FEM model solution, complying with the requirements of sub-chapter 14.7.2, shall be assessed.

In region of notches, stresses, subject to assessment, shall be determined by extrapolation method – on the basis of values in two centres, the closest to the notch, finite elements (Fig. 14.7.5.1).

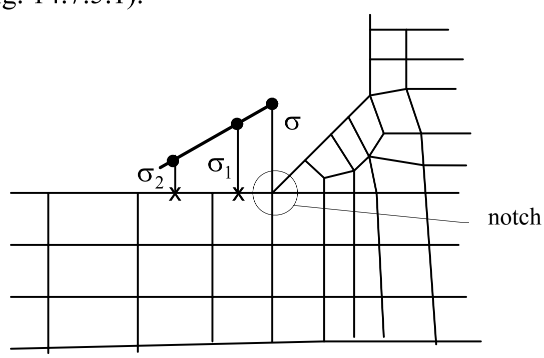


Fig. 14.7.5.1 Principle of stresses values extrapolation

14.7.5.2 In the case of longitudinal plating's stiffeners, transferring normal stresses from the hull general bending or torsion, as well as stresses from the zone bending and local bending, level of summary stresses shall be assessed.

Stresses from static loads and stresses from the wave loads, exceeded with the probability 10^{-4} , shall be directly summarized (considering their signs). It means, that for calculations in the case of general bending 0.59 value of the bending moment M_w determined in 15.5 is assumed, and the wave load, for zone and local bending analysis shall be assumed in accordance with 17.6.

14.7.5.3 The values of permissible stresses in the face plates of plating stiffeners are following:

– normal stresses the from local bending: $\sigma = 160k$, [MPa];
– summary normal stresses from the local and zone bending: $\sigma = 180k$, [MPa];
– summary normal stresses from the general, local and zone bending: $\sigma = 225k$, [MPa].

Mean values of the tangent stresses in the stiffeners webs shall not be greater than $90k$, [MPa].

Note: the above stresses values are applicable for in-port conditions (loading operations), where zero value of the wave loads may be assumed.

14.7.5.4 Checking of the stiffeners' brackets strength consists in assessment of the normal stresses level along free edges of the bracket, in the middle of its length.

Permissible value of these stresses, with consideration of stiffeners local and zone bending, is $180k$, [MPa]. The brackets fulfilling the above criterion need not be checked for loads including general bending or torsion of the hull.

Note: due to criterion of fatigue life (see Chapter 16), checking of the stresses level in the region of the brackets ends may be required.

14.7.5.5 Values of stresses determined by FEM in the area of the notches, other than stiffeners' brackets, shall be separately considered by PRS in each particular case.

14.7.6 Report on FEM Calculations

14.7.6.1 Report on FEM calculations, in a scope identical, as determined in 14.4.5, is required.

15 LONGITUDINAL STRENGTH

15.1 General

15.1.1 Application

15.1.1.1 The final scantlings of longitudinal hull structure members, which are to comply with the requirements of local strength (Chapter 13) and zone strength (Chapter 14) of the hull structure are also to comply with the requirements of hull girder bending and shear strength given in the present Chapter. These requirements apply to steel ships intended for navigation in unrestricted area. Ships having one or more features given below are subject to special consideration by PRS:

– main dimensions ratios: $L_0 / B < 5$, $B/H > 2.5$,
– block coefficient $\delta < 0.6$,
– non-typical design of the ship.

15.1.1.2 The values of the wave bending moments and shear forces applied in the present Part of the *Rules* correspond to the values which can be exceeded with probability equal to 10^{-8}. Values in this form are applied at determining the required section modulus and shear cross-sectional area of the hull, as well as at checking the buckling and ultimate strength of the hull. In other cases, where wave hull bending stresses are combined with stresses determined on the basis of zone or local strength analysis of the structure, the Rule values of wave bending moments and shear forces may be reduced to the following values:

$$M_{wr} = 0.59\, M_w \text{, [kNm]} \qquad (15.1.1.2\text{-}1)$$

$$Q_{wr} = 0.59 Q_w \text{, [kN]} \qquad (15.1.1.2\text{-}2)$$

M_w – vertical wave bending moment, [kNm], determined according to 15.5;
Q_w – wave component of hull shear force, [kN], determined according to 15.10.

15.1.1.3 The scantlings of longitudinal members taking part in the longitudinal strength of the hull girder are to comply with the requirements for buckling strength given in 13.3.

15.1.1.4 For ships with high speed and large flare in forebody increasing of design values of wave bending moment and shear force by applying requirements of 15.5.5.2 and 15.10.2 may be required. The above adjustment means increasing longitudinal strength in the hull bow part.

15.1.1.5 The longitudinal strength of relatively small ship's breadth is to comply with the requirements of 15.12.

15.1.1.6 For ships with large deck openings, the combined effects of hull girder bending, shear and torsion related to local bending and shear stresses may have to be taken into account.

15.1.1.7 Additional requirements for the scantlings of hull structural members may be given, taking into consideration specific features of the ship regarding the load conditions and structure.

15.1.2 Definitions

C_w – wave coefficient, as given in 17.5.2.2.
I_n – moment of inertia of the hull cross-section for the transverse neutral axis, [cm^4].
M_s – design still water bending moment, [kNm].
M_w – vertical wave bending moment, [kNm].
Q_s – design still water shear force, [kN].
Q_w – design wave shear force, [kN].
S_n – first moment of area of the longitudinal structure members above or below the horizontal neutral axis, taken about this axis, [cm^3].
z_n – vertical distance from the base line or strength deck line to the neutral axis of the hull girder, whichever is relevant, [m].
τ – allowable shear stress, [MPa].
σ – allowable bending stress, [MPa].

15.2 Hull Section Modulus

15.2.1 The section modulus about the horizontal neutral axis, determined according to 15.7, is not to be less than:

$$W = \frac{M_s + M_w}{\sigma} \cdot 10^3 \text{, [cm}^3\text{]} \qquad (15.2.1)$$

M_s – hull still water bending moment, calculated according to 15.4, [kNm];
M_w – hull wave bending moment, determined according to 15.5, [kNm];
σ = 175 k, [MPa], within $-0.2\,L_0 \le x \le +0.2\,L_0$,
σ = 105 k, [MPa], within $x \le -0.4\,L_0$ and $x \ge +0.4\,L_0$.

Between the specified regions, the value of σ varies linearily. In each n case the hull girder section modulus W is to comply with the requirements given in 15.2.2.

15.2.2 The midship section modulus related to the deck and the keel is not to be less than:

$$W_0 = \frac{C_{wo}}{k} L_0^2 B\left(\delta + 0.7\right) \text{, [cm}^3\text{]} \qquad (15.2.2)$$

The value of δ is not to be taken less than 0.6.

C_{wo} – see C_w according to 17.2.2, and:

- for ships with length $L_0 \ge 100$ m
  C_{wo} is taken according to 17.5.2.2;
- for ships with length $L_0 < 100$ m
  $C_{wo} = 5.7 + 0.022\,L_0$, but not less than 7.0;

- for ships of restricted service, the coefficient C_{wo} may be reduced:
  - by 5% for service area II,
  - by 15% for service area III.

The minimum value of section modulus is to be generally maintained within $-0.2\ L_0 \leq x \leq +0.2\ L_0$. It may be, however, gradually reduced from the midship towards fore and aft end of ship, provided the stresses due to still water and wave bending moments do not exceed the values allowed for the middle part of the ship.

15.2.3 In slender ships it may happen that to keep the required section modulus within the end regions of the middle part of the ship it would be necessary to increase scantlings of hull longitudinal members within these regions.
In such cases PRS may accept not increased scantlings, provided the scantlings of the members and their material groups are kept unaltered within the whole midship body and the proper tapering of material and structural member scantlings towards the ends of the ship is made.

15.2.4 The scantlings of longitudinal members outside amidships may be gradually reduced to the scantlings determined by the local strength for the ship ends. In the cases given in 15.1.1 or determined by the ship structural design, special consideration of the hull section modulus in other places along the ship's length may be required.

15.2.5 In ships without parallel middle body or with long superstructures in the middle part, additionally direct calculations FEM of stresses due to general bending, according to principles given in 14.6, assuming M_s and M_w as in 15.4 and 15.5, may be required. Values σ given in 15.2.1 shall be then considered as permissible values for normal stresses to the ship axis.

15.3 Moment of Inertia of Hull Cross-section

The moment of inertia of ship's hull cross-section is not to be less than:

$$I_n = 3C_w L_0^3 B\left(\delta + 0.7\right), \text{ [cm}^4\text{]}. \qquad (15.3)$$

15.4 Still Water Bending Moment

15.4.1 The design still water bending moments are to taken as the maximum value in each section along the ship's length as obtained from calculation for design loading conditions. The realistic full and part load conditions, realistic amounts of bunker and stores at departure and arrival, are to be taken into account, including ballast and docking conditions.

15.4.2 The positive sense of bending moments and shear forces, applied in the present Rules, are as shown in Fig. 15.4.2.

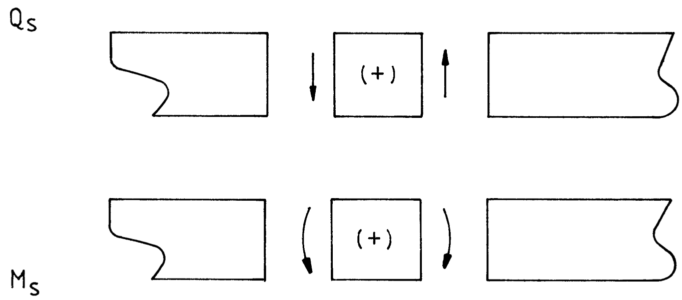


Fig. 15.4.2 Positive sense of bending moments and shear forces

15.4.3 For the ships with length $L_o \geq 100$ m, the design still water bending moment M_s amidships is to be taken as the maximum absolute value of the bending moment according to 15.4.1 but in the midship part not less than:

$$M_{s0} = M_{s0u} = 0.065 C_w L_0^2 B(\delta + 0.7), \text{ [kNm]} \quad (15.4.3\text{-}1)$$

in sagging, and

$$M_{s0} = M_{s0w} = C_w L_0^2 B(0.1225 - 0.015\delta), \text{ [kNm]} \quad (15.4.3\text{-}2)$$

in hogging.

If the value of block coefficient is less then 0.6, $\delta \geq 0.6$ is to be taken for calculations.

For ships with space arrangement giving small possibilities for variation of the distribution of cargo and ballast, the value of M_{so} may be dispensed with as the design basis for determining the scantlings of hull structural members.

15.4.4 If for stress analysis or buckling control of structural members determination of values of bending moments M_s, outside the middle part of the ship, is required, then these values, for each considered cross-section of the hull, with the length $L_0 \geq 100$ m, shall be determined according to 15.4.1, and the above values are not to be less than those determined from the formula:

$$M_{sx} = k_{sm} M_{s0}, \text{ [kNm]} \quad (15.4.4)$$

M_{s0} – acc. to 15.4.3
$k_{sm} = 1.0$ for the midship body: $-0.2\,L_0 \leq x \leq +\,0.2\,L_0$,
$k_{sm} = 0.15$ for sections: $x = -0.4\,L_0$ and $x = +\,0.4\,L_0$,
$k_{sm} = 0.0$ for sections: $x = -0.5\,L_0$ and $x = +\,0.5\,L_0$.

The k_{sm} value between the above specified areas is to be obtained by linear interpolation.

15.4.5 The minimum value of still water bending moment of the hull with the length $L_o < 100$ m is to be determined from the formula:

$$M_s = M_{so} = 0.006 L_0^3 B(\delta + 0.7), \text{ [kNm]} \quad (15.4.5)$$

Where absolute value of still water bending moment M_{sl}, determined as specified in 15.4.1 exceeds M_{so}, then $M_s = M_{sl}$ is to be taken.

The determined value of M_s is applicable within $-0.2\ L_0 \le x \le +0.2\ L_0$.

Beyond this area, M_s may be linearly reduced to zero at $x = -0.5\ L_0$ and $x = +0.5L_0$.

15.5 Wave Bending Moment

15.5.1 Vertical Wave Bending Moment

The design vertical wave bending moment M_w amidships within $-0.1\ L_0 < x < +0.15\ L_0$ is to be taken as:

$$M_w = M_{wu} = -0.11\, C_w L_0^2\, B(\delta + 0.7)\text{, [kNm]} \qquad (15.5.1\text{-}1)$$

for negative moment (sagging), and

$$M_w = M_{ww} = 0.19\, C_w L_0^2\, B\delta\text{, [kNm]} \qquad (15.5.1\text{-}2)$$

for positive moment (hogging).

The following values are to be taken:

δ ≥ 0.6;

C_w – see 17.5.2.2.

15.5.2 Distribution of M_w along the Ship's Length

15.5.2.1 When required in connection with stress analysis or buckling control, the wave bending moments M_w, at arbitrary positions along the ship's length, are not to be less than M_{wx} values determined from the formula:

$$M_{wx} = k_{wm} M_w\text{, [kNm]} \qquad (15.5.2.1)$$

$k_{wm} = 1.0$ within $-0.1\ L_0 \le x \le +\ 0.15\ L_0$ for ships with $L_0 \ge 100$ m,

$k_{wm} = 1.0$ within $-0.1\ L_0 \le x \le +\ 0.1\ L_0$ for ships with $L_0 < 100$ m,

$k_{wm} = 0.0$ in sections $x = -0.5\ L_0$ and $x = +\ 0.5\ L_0$.

The k_{wm} value is to be varied linearly between the midship and end areas (see Fig. 15.5.2.2).

15.5.2.2 For ships with high speed or large flare in the forebody an adjusted value of k_{wm} is to be taken in formula 15.5.2.1 within $x \ge +\ 0.1\ L_0$. The adjustment depends on the value of parameters $C_a = C_{av}$ and $C_a = C_{af}$, whichever of the adjusted values of k_{wm} is the greater.

$$C_{av} = \frac{C_v v}{\sqrt{L_0}} \qquad (15.5.2.2\text{-}1)$$

$$C_{af} = \frac{C_v v}{\sqrt{L_0}} + \frac{F_{pd} - F_{wd}}{L_0 z_{pd}} \qquad (15.5.2.2\text{-}2)$$

$C_v = \frac{\sqrt{L_o}}{50}$; $C_v \le 0.2$ is to be taken;

L_0 and v – see 1.2.2 of Part A;

F_{pd} – projected area in the horizontal plane of upper deck, including any forecastle deck, in way of $x \ge +0.3\ L_0$, [m^2];

F_{wd} – area of waterplane at draught T in way of $x \ge +0.3\ L_0$, [m^2];

z_{pd} – vertical distance from the summer load waterline to deck line of the projected deck at FP, [m].

The values of k_{wm} coefficients adjusted for parameter $C_a = C_{av}$ apply to loading conditions causing hogging or sagging still water bending moments. The values of coefficient k_{wm} adjusted for $C_a = C_{af}$ apply to loading conditions causing sagging only.

If $C_{af} \ge 0.5$, the adjustment of k_{wm} coefficients for $C_a = C_{av}$ parameter is not to be made.

The adjusted values of k_{wm} are as follows:

– for $C_a \le c_1$
  k_{wm} is to be determined according to 15.5.2.1 (without adjustment),
– for $C_a \ge c_2$
  $k_{wm} = 1.2$ within $-0.02\ L_0 \le x \le +0.15\ L_0$,
  $k_{wm} = 0.0$ for $x = -0.5\ L_0$ and $x = 0.5\ L_0$,
– for intermediate values $c_1 < C_a < c_2$, and for x co-ordinate, the values of k_{wm} coefficient are to be determined by linear interpolation;
  c_1 and c_2 – the limit values of C_a:
  $c_1 = 0.28$; $c_2 = 0.32$ when $C_a = C_{av}$ and
  $c_1 = 0.40$; $c_2 = 0.50$ when $C_a = C_{af}$.

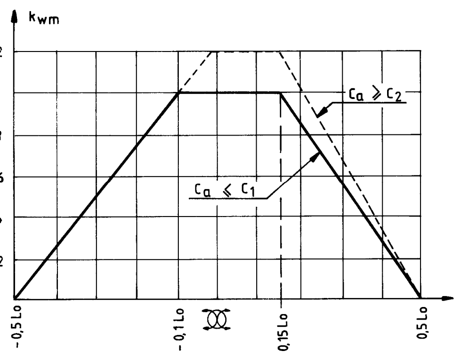


Fig. 15.5.2.2 Distribution of k_{wm} along the ship's length

15.6 Extent of High Strength Steel Application

15.6.1 The vertical extent of HS steel application measured from the bottom or deck toward hull cross-section neutral axis is not to be less than that determined from the formula:

$$z_{HS} = z_n \frac{f - k}{f}, \text{ [m]} \qquad (15.6.1)$$

k – material factor (according to 2.2.1) for the members located more than z_{HS} from the deck or bottom (see Fig. 15.6.1);

f – see 13.1.2;

z_n – see 15.1.2.

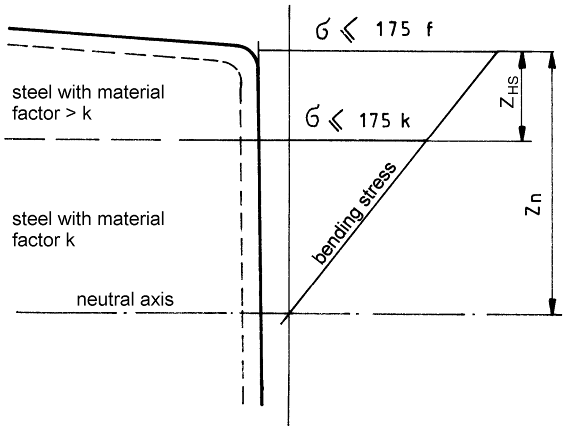


Fig. 15.6.1 Vertical extent of HS steel application

15.6.2 The longitudinal extent of HS steel application (x_{HS}) in the bottom or deck is not to be less than that given in Fig. 15.6.2.

Fig 15.6.2a shows application of HS steel members amidships (within $-0.2\ L_0 \leq x \leq +0.2\ L_0$) extended, without the change of material and scantlings, to the point where their scantlings become equal to those required at that point for members made of NS steel.

Fig 15.6.2b shows the application of HS steel members also outside amidships reducing, within this area, the scantlings of longitudinal members according to the requirements of present Part of the *Rules*. Outside the area of HS steel application, these members are extended without the change of material and scantlings, to the point where their scantlings become equal to those required at that point for members made of NS steel.

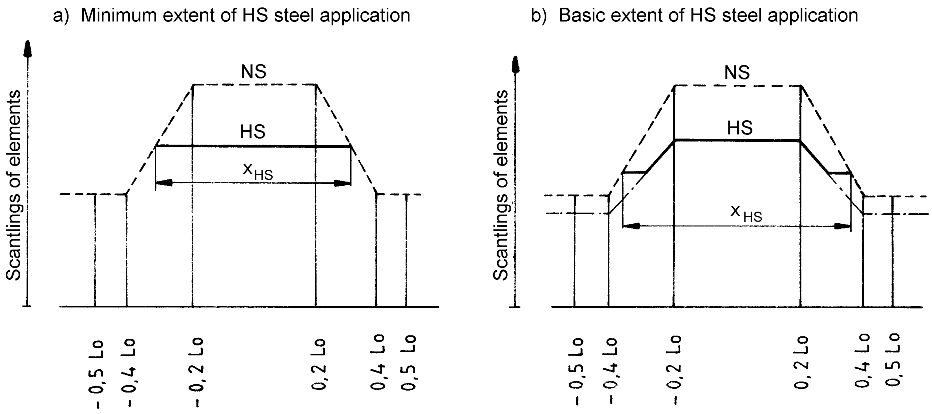


Fig. 15.6.2 Longitudinal extent of HS steel

15.7 Geometrical Data on the Hull Cross-section as Built

15.7.1 The Section Modulus and Moment of Inertia of Hull Section

15.7.1.1 When calculating the hull cross-section moments of inertia and section modulus, the following is to be taken into account:

– the sectional area of continuous longitudinal strength members (the effect of openings being taken into consideration according to 15.7.2);
– the value of effective sectional area of longitudinal strength members between rows of hatch openings is to be multiplied by factor 0.6 or is to be determined on the basis of stress analysis carried out in a way agreed with PRS;
– superstructures which do not form a strength deck are not to be included in the sectional area;
– deckhouses, bulwarks and non-continuous hatch side coamings are not to be included in the sectional area.

When calculating the hull section modulus, continuous longitudinal strength members may be taken into consideration if:

– the scantlings of the cross-sectional area of the members are maintained within $-0.2\ L_0 \le x \le +0.2\ L_0$,
– outside the above-mentioned region, the reduction of the member scantlings is gradual,
– the change of strength properties of the applied steel complies with the requirements of 15.6.

In special cases, considering ship type, hull form and loading conditions, the scantlings of strength members may be gradually reduced towards the ends of midship part of the ship ($-0.2\ L_0 \le x \le +0.2\ L_0$), bearing in mind the desire not to inhibit the vessel's loading flexibility.

15.7.1.2 The actual hull section modulus generally refers to the base plane and strength deck line at side.

For ships with continuous longitudinal hatch coamings or other continuous longitudinal strength members above the strength deck, effectively supported by longitudinal bulkheads or deep girders, the Rule section modulus is to be referred to the line above the neutral axis at the distance determined by the formula:

$$z_t = (z_n + z_a)\left(0.9 + 0.2\frac{y_a}{B}\right), \text{ [m]} \tag{15.7.1.2}$$

but not less than z_n;

z_n – see 15.1.2;

z_a – distance from the strength deck to the member in question, [m];

y_a – horizontal distance from the ship centre plane to the member in question, [m].

y_a and z_a co-ordinates are to be selected to obtain the greatest value of z_t.

15.7.2 Determining the Influence of Openings on Effective Cross-sectional Area of the Hull

15.7.2.1 When calculating the midship section modulus, openings exceeding 2.5 m in length or 1.2 m in breadth and scallops, where scallop welding has been applied, are to be deducted from the sectional areas of continuous longitudinal members.

15.7.2.2 Smaller openings (manholes, lightening holes), as well as ineffective sections of cross-sectional area of longitudinal structural members need not be deducted when calculating the cross-sectional area of these members, provided that the sum of their breadths in one transverse section does not reduce the section modulus at deck or bottom by more than 3%. The height of these openings in longitudinals and longitudinal girders is not to exceed 25% of the web depth (75 mm for scallops), and the distance between single openings or groups of openings along the stiffener (girder) is not to be less than 10 times the height of opening. The sum of breadths of smaller openings in one transverse section of bottom or deck, equal to 0.06 (B – Σ b_i) (Σ b_i – the sum of breadth of openings), may be considered as equivalent to the above reduction in section modulus.

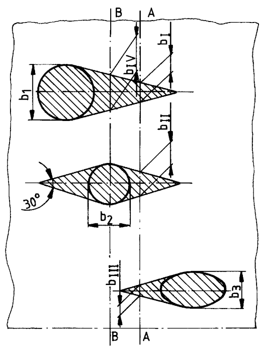


Fig. 15.7.2.2

Examples of determining the influence of openings on the effective sectional area

15.7.2.3 It is assumed that the openings which need not be deducted are arranged approximately symmetrically about ship's centreline and that the openings do not cut any continuous longitudinal or girder included into the midship section area calculations.

15.7.2.4 The cross-section area of openings subjected to deduction may be compensated as a whole or in part by increased plate thickness, additional longitudinal stiffeners or increase of sectional area of existing longitudinals or girders in way of the opening.

Compensation is to be extended accordingly outside the opening edge. Other compensation methods may be applied upon PRS agreement.

15.7.2.5 When calculating the total breadth of openings in one cross-section, the openings are assumed to have longitudinal extension as shown by the shaded areas in Fig. 15.7.2.2, inside tangents at angle 30° to each other, and symmetric about the longitudinal axis. For instance, the total design breadth of openings in section A-A is:
$b_{A\text{-}A} = b_I + b_{II} + b_{III}$, and in section B-B: $b_{B\text{-}B} = b_2 + b_{IV}$.

15.8 Shear Strength

15.8.1 Application

15.8.1.1 For ships with the single sides, shear strength, in general bending conditions, is sufficient if the side thickness is not less than determined from the formula 15.11.1.

15.8.1.2 Shear strength in general bending conditions of hulls with longitudinal bulkheads is to be checked by determination of the sheer stresses values resulting from force Q_s+ Q_w (Q_s- from 15.9.1; Q_w from 15.10, in particular points of the hull cross-section.

In calculations bending of thin-walled beams may be applied.

Calculated maximum value of sheer stresses shall not be greater than $\tau = 110k$, MPa.

15.8.1.3 Checking of the shear strength in the scope required in 15.8.1.2 may be performed within FEM analysis according to requirements given in 14.4, for the values Q_s, Q_w and τ as in 15.8.1.2.

15.9 Still Water Shear Forces

15.9.1 Loading Conditions

Still water shear forces, Q_s, are to be determined at each cross-section of the hull along the ship's length for design loading and ballast conditions as specified in 15.4.1. For sign convention, see Fig. 15.4.2.

15.9.2 Distribution of Shear Forces along the Ship's Length

The design values of still water shear forces, determined as required in 15.9.1, are to comply with the following requirements:

$$Q_s \geq k_s Q_{so}\text{, [kN]} \tag{15.9.2-1}$$

$$Q_{so} = \frac{5M_{so}}{L_0}\text{, [kN]} \tag{15.9.2-2}$$

M_{so} – still water bending moment – see 15.4.3 or 15.4.5, [kNm];
k_s = 0 for $x = -0.5\ L_0$ and $x = +0.5\ L_0$,
k_s = 1 for $-0.35\ L_0 \leq x \leq -0.2\ L_0$,
k_s = 0.8 for $-0.1\ L_0 \leq x \leq +0.1\ L_0$,
k_s = 1 for $+0.2\ L_0 \leq x \leq +0.35\ L_0$.

The k_s values are varied linearly in the intermediate regions.

For ships with space arrangement giving small possibilities for variation of the cargo and ballast distribution, the value of Q_{so} may be dispensed with as the design basis for determining the scantlings of hull structural members.

15.10 Wave Shear Forces

15.10.1 The design values of wave shear forces in particular cross-sections of the hull along the ship's length are to be determined from the following formulae:

$$Q_{wp} = 0.3k_p C_w L_0 B(\delta + 0.7)\text{, [kN]} \tag{15.10.1-1}$$

$$Q_{wn} = -0.3k_n C_w L_0 B(\delta + 0.7)\text{, [kN]} \tag{15.10.1-2}$$

Q_{wp} – positive wave shear force applied for hull cross-sections, for which the still water shear force is positive;
Q_{wn} – negative wave shear force applied for hull cross-sections, for which the still water shear force is negative.

The shear force sign is to be determined according to Fig. 15.4.2.

k_p = 0 for $x = -0.5\ L_0$ and $x = +0.5\ L_0$,
$k_p = \frac{1.59\delta}{\delta + 0.7}$ for $-0.3\ L_0 \leq x \leq -0.2\ L_0$,
k_p = 0.7 for $-0.1\ L_0 \leq x \leq +0.1\ L_0$,
k_p = 1 for $+0.2\ L_0 \leq x \leq +0.35\ L_0$.

The values of k_p are varied linearly in the intermediate regions (see Fig. 15.10.1).

k_n = 0 for $x = -0.5\ L_0$ and $x = +0.5\ L_0$,
k_n = 0.92 for $-0.3\ L_0 \leq x \leq -0.2\ L_0$,
k_n = 0.7 for $-0.1\ L_0 \leq x \leq +0.1\ L_0$,
$k_n = \frac{1.73\delta}{\delta + 0.7}$ for $+0.2\ L_0 \leq x \leq +0.35\ L_0$.

The values of k_n are varied linearly in the intermediate regions (see Fig. 15.10.1).

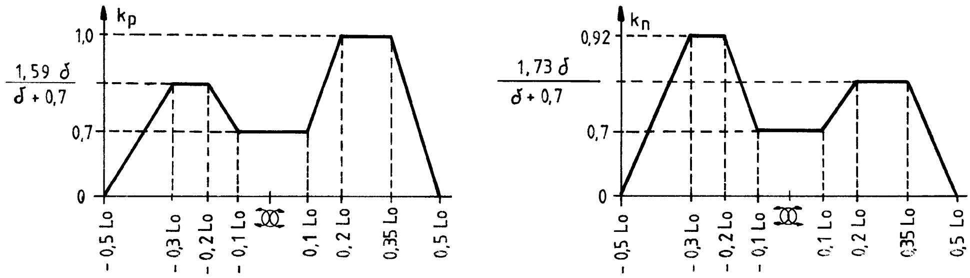


Fig. 15.10.1 Factors k_p and k_n

15.10.2 For ships with high speed or large flare in the forebody, the adjusted values of k_p and k_n are to be applied in formulae 15.10.1-1 and 15.10.1-2. The adjustment depends on the value of parameters $C_a = C_{av}$ and $C_a = C_{af}$. The adjusted values of k_p and k_n may be determined by multiplying their values, determined from 15.10.1, by the following coefficient r :

for $C_a < c_1$ and $C_a > c_2$ $r = 1.0$ within $-0.5\ L_0 \le x \le +0.5\ L_0$;
for $c_1 \le C_a \le c_2$ $r = 1.0$ within $x \le +0.1\ L_0$,
$r = 1.2$ within $0.2\ L_0 \le x \le 0.35\ L_0$,
$r = 1.0$ at cross-section $x = 0.5\ L_0$.

For intermediate values of C_a and x, the value of r is to be determined by linear interpolation.

For C_a, C_{av}, C_{af}, c_1, c_2 – see 15.5.2.2.

15.11 Requirements for Structures Subjected to Shear Forces

15.11.1 In ships without effective longitudinal bulkheads, the thickness of the side (sum of outer and inner side thicknesses – for double skin construction) is not to be less than that determined from the formula:

$$t = \frac{0.5(Q_s + Q_w)}{\tau}\frac{S_n}{I_n}10^2\text{, [mm]} \qquad (15.11.1)$$

where:

τ = 110 k, [MPa] unless lesser value results from the buckling strength requirements.

S_n = static moment for the neutral axis of cross-sectional area of the effective longitudinal members positioned between the vertical level at which the shear stress is being calculated and the vertical extremity of effective longitudinal members, taken at the section under consideration, [cm^3],

I_n = moment of inertia for the neutral axis of the cross-section area of the longitudinal hull members, [cm^4].

When calculating t, S_n / I_n may be taken equal to 1/90 H for the neutral axis of the cross-section.

15.11.2 In hulls with longitudinal bulkheads, checking of the strength from transverse forces' load according to 15.8.1.2 and 15.8.1.3 is obligatory.

15.12 Bending of the Hull in the Horizontal Plane

15.12.1 For ships with the length $L_0 \geq 100$ m the hull section modulus in a mid part of the ship for the vertical neutral axis shall not be less then modulus obtained from the formula:

$$W_{0h} = \frac{5}{k} L_0^{9/4} (T + 0{,}3B)\delta \text{, [cm}^3\text{]} \qquad (15.12.1)$$

15.12.2 Requirements of 15.2.1 need not be complied with, provided that the following condition is fulfilled:

$$\sigma_s + \sqrt{\sigma_w^2 + \sigma_{wh}^2} \leq 195k \text{, [MPa]} \qquad (15.12.2)$$

where:

σ_s – stresses due to general bending moment M_s determined according to 15.4, [MPa];

σ_w – stresses due to general bending moment M_w determined according to 15.5, [MPa];

σ_{wh} – stresses due to general bending moment in the vertical plane M_{wh} determined according to 15.12.3, [MPa].

The condition 15.12.2 shall be checked for the side shell at the ships bilge and at the connection of the side with the strength deck.

15.12.3 Horizontal wave bending moment M_{wh} shall be determined from the formula:

$$M_{wh} = 0.22 L_0^{9/4} (T + 0.3B\delta) \left(1 + cos\frac{2\pi x}{L_0}\right) \text{, [kNm]} \qquad (15.12.3)$$

x – coordinate according to Fig. A/2.3.1.

15.13 Hull Torsion

15.13.1 Application

15.13.1.1 In the case of the hulls of ships with relatively wide openings in the strength deck, PRS may require checking of the strength and stiffness of the hull with consideration of its torsion.

15.13.1.2 The strength analysis within the scope as in 15.13.1.1 is always required in situation, where the hatch openings in the strength deck fulfil the conditions:

$$\frac{b}{B_1} > 0.6$$
$$\frac{l}{l_m} > 0.7 \qquad (15.13.1.2)$$

where:

b – width of the hatches, measured between the outmost on each sides longitudinal coamings of the hatch openings, [m];

B_1 – breadth of the strength deck measured in the middle of the hatch length, [m];

l – length of the hatch opening, [m];

l_m – longitudinal distance between centres of the transverse strakes between hatches, adjacent to the considered hatch, [m].

15.13.2 Analysis Method and Calculation Loads

15.13.2.1 Deformations and normal stresses in area of the strength deck, for the ship set diagonally to the wave, where below listed loads and the hull deformations occur, shall be determined.

The values of normal stresses σ and the hull deformations under cumulative effect of the following loads shall be assessed in accordance with the criteria of 15.13.4:

- general bending of the hull in a vertical plane, on still water and wave,
- general bending of the hull in a horizontal plane (on wave),
- torsion of the hull on still water and wave,
- zone bending of the deck strakes, adjacent to the sides, due to impact of overboard water.

15.13.2.2 The calculations may, in general, be made with application of: the bent beam model – for the hull general bending analysis, and the model of torsion of the thin wall constrained beam – for the hull torsion analysis.

Constraint of the open part of the hull (with wide openings in the deck) by the parts of the hull beyond the open part, shall be taken into account.

In calculations the requirements given in *Publication No. 24/P –Strength Analysis of the Container Ship Hull* may be applied.

15.13.2.3 In the case of the hulls of small block coefficient value, it is recommended to perform calculations by applying the recommendations for the FEM calculation model given in 14.4. Calculation model should include the structure of the entire hull of the ship.

15.13.3 Hull Torsional Moment

15.13.3.1 The total hull torsional moment, M_t, is a sum of the still water torsional moment, M_{tc}, and wave torsional moment, M_{tw}, with the value corresponding to the probability of its excess equal to 10^{-8}.

15.13.3.2 The values of $M_{tc} \neq 0$ shall be applied only in situations, where arrangement of the ballast tanks and stores, as well as cargo and magazine spaces enable asymmetrical distribution of the ship's masses of significant values. The values of $M_{tc}(x)$ shall be determined for the most unfavourable, realistic distributions of the weights.

In the ships, where the space division and complex service makes impossible to generate significant values of M_{tc}, $M_{tc}(x)= 0$ may be assumed.

15.13.3.3 Wave torsional moment, M_{tw}, consists of two components: M_{tw1} i M_{tw2}, calculated from the formulae:

$$M_{tw1} = 126K_2 C_w B L_0^2 \left(\delta\alpha_1(x) - 0.5\alpha_3(x)\right)\cdot 10^{-3}\text{, [kNm]} \quad (15.3.3.3\text{-}1)$$

$$M_{tw2} = 63C_w B L_0^2 K_1 \alpha_2(x)\cdot 10^{-3}\text{, [kNm]} \quad (15.3.3.3\text{-}2)$$

where:

$K_1 = 2x_1 x_0 \left(1 + 3.6(C_{WL} - 0.7)\right)\dfrac{B}{L_0}$;

$K_2 = 10x_2 \dfrac{T}{L_0}\dfrac{e}{B}$;

$x_1 = 1 - 8\dfrac{T}{L_0}$;

$x_2 = 1 - 4\dfrac{T}{L_0}$;

$x_0 = 1 - 4C_{WL}\dfrac{B}{L_0}$;

C_{WL} – block coefficient of the design waterline,

e – vertical distance from the torsion centre of the hull midship section, to the point at height of $0.6T$ above the base plane, [m],

C_w – wave coefficient, determined in accordance with 17.5.2.2,

$\alpha_1(x) = \sin\dfrac{2\pi x}{L_0}$;

$\alpha_2(x) = \dfrac{1}{2}\left(1 - \cos\dfrac{2\pi x}{L_0}\right)$;

$\alpha_3(x) = \sin\dfrac{3\pi x}{L_0}$;

x – distance from the aft perpendicular (see axis x at Fig. 15.13.3.5, [m].

15.13.3.4 In calculations of stresses and deformations in the hull, taking into account the torsion, two distributions of the total moment twisting the ship, along the ship's axis shall be considered:

$$M_t = M_{tw1} + M_{tw2} + M_{tc}$$
$$M_t = M_{tw1} - M_{tw2} - M_{tc} \quad (15.13.3.4)$$

Sense of M_t is to be assumed in accordance with Fig. 15.13.3.5.

15.13.3.5 Positive senses of the torsional moment and remaining internal forces are presented on Fig. 15.13.3.5.

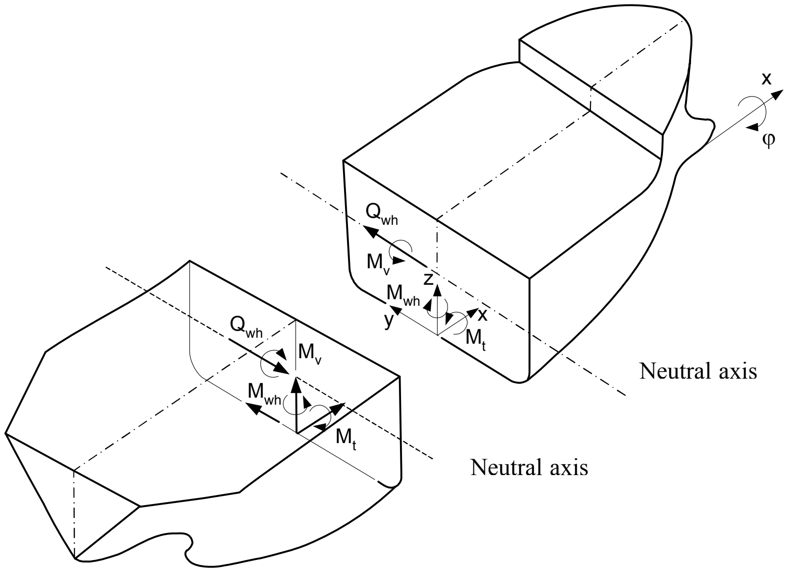


Fig. 15.13.3.5 Positive senses of the internal forces in the hull

15.13.4 Strength and Rigidity Criterion

15.13.4.1 Total stresses σ_{tot} in the strength deck and in the continuous longitudinal hatch coaming, calculated by the method specified in 15.13.2.2 shall meet the conditions:

$$\sigma_{tot} = \sigma_s + \sigma_{tc} + \sigma_{bc} + 0.35\sigma_w + 0.59(\sigma_{wh} + \sigma_{wt} + \sigma_{bw}) + \sigma_{bp} \le 195k \text{ , [MPa]} \quad (15.3.4.1\text{-}1)$$

$$\sigma_{tot} = \sigma_s + \sigma_{tc} + \sigma_{bc} + 0.6\sigma_w + \sigma_{wt} + \sigma_{bw} \le 175k \text{ , [MPa]} \quad (15.3.4.1\text{-}2)$$

where:

σ_s – stresses from general bending of the hull in still water, calculated for bending moment values specified in accordance with 15.4;

σ_{tc} – stresses in result of constrained torsion of the hull by the M_{tc} (see 15.13.3);

σ_{bc} – stresses in result of the deck bending in a horizontal plane in effect of reaction of the cross deck structure, deformed due to deplanation of the cross hull sections, induced by M_{tc};

σ_w – stresses from the general bending of the hull by the wave moment M_w determined in accordance to 15.5;

σ_{wh} – stresses from the general bending of the hull by the moment M_{wh} determined in accordance to 15.12.3;

σ_{wt} – stresses in result of the hull tensioned bending by the moment M_{tw} (see 15.13.3.3);

σ_{bw} – as σ_{bc} but from the moment M_{tw};

σ_{bp} – stresses in result of the deck bending in the horizontal plane due to pressures acting on the hull sides.

Note: stresses σ_{tc} i σ_{wt} include influence of the transverse cross deck structure on values of bi-moments in the transfer hull sections.

Stresses σ_{tot} shall be determined in points C, D, E presented on Fig. 15.13.4.1, for both sides of the ship, in the following transfer sections:

– in the end parts' sections of the hull with the wide deck openings;;
– in the frame sections in the middle of the large deck openings;
– in the frame sections, in which peripheral edges of the cross deck structure are located.

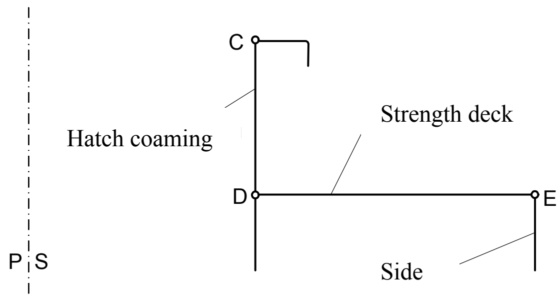


Fig. 15.13.4.1

At determining σ_{tot}, stresses components σ shall be assumed with the following signs:

– sign σ_s is adequate to the sign of the moment M_s. If in the considered case the ship is in sagging, then $\sigma_s < 0$. In case of the ship hogging, $\sigma_s > 0$;
– sign σ_w shall be assumed the same as sign σ_s;
– component M_{tw1} of the torsional moment, assumed positive, has the sense consistent with Fig. 15.13.3.5. Stresses σ_{wh}, the sign of which results from interrelation between signs of M_{wh} and M_{tw1}, shall be assumed as a stresses stretching the left side plating, and compressing the left side plating;
– at determining σ_{tc} i σ_{wt}, M_t sense, in accordance with Fig. 15.13.3.5 shall be applied. Two distributions of M_t, in accordance with 15.13.3.4, shall be taken into account;
– signs σ_{bc} i σ_{bw} correspond directly to senses of the transfer forces in the cross deck, which result from the assumed sense of the torsional moment M_t;
– sign σ_{bp} results from analysis of the side bending under the pressure acting from outside.

15.13.4.2 In the case of FEM calculations in accordance with 15.13.2.3, for direct determination of σ_{tot} corresponding to components of the stresses in formulae 15.13.4.1-1 and -2, the proper load of the model shall be applied.

In general, modelling of values M_s, M_w, M_{tc}, M_{tw} i M_{wh} in a form of properly selected values of the continuous load, acting in planes of sides and horizontal plane, is permitted.

15.13.4.3 The difference in diagonals length of the hatch openings meeting conditions given in 15.13.1.2, effected by the hull deformation under the influence of the torsional moment determined in 15.13.3, shall not exceed 25 mm.

In the case of smaller openings, their permissible deformations are subject to special consideration by PRS – taking into account the limitations arising from the hatch covers' structure and their sealing system.

15.14 Hull Loading Control

15.14.1 Ship Loading Manual

15.14.1.1 All ships with length over 65 m shall be provided with the document called *Ship Loading Manual.*

In justified cases PRS may require to develop such document for ships with length less than 65 m.

15.14.1.2 Loading manual shall contain the following information:
– allowable local loading for the structure with the loads of stores or cargo (load of inner bottom, decks and platforms, hatch covers, etc.);
– allowable parameters of the transported vehicles (allowable axle load and minimum dimensions of the single wheel imprint, axle load and minimum width of the vehicle track and its load in kN/m) and helicopters (maximum starting mass).

15.14.1.3 In the case of ships, where possibility exists of various distribution, in longitudinal and transverse direction, of significant masses of stores and cargo, the following information in *Loading Manual* may also be required:
– recommended typical loading conditions and permissible values of still water bending moments, lateral loads and torsional moments (if torsion is meaningful);
– the results of calculations of bending moments, lateral loads and torsional moments, in a form of tables and diagrams;
– ship loading plan (sequence of loading/unloading from its start until permissible full capacity) – for typical loading conditions.

15.14.2 Ship Loading Instrument

15.14.2.1 In the case of ships with characteristics listed in 15.14.1.3, provision the ship with loading instrument (loading calculator) may also be required. It is a computer with a software enabling calculation of internal forces in the hull, for given distribution of stores and cargo masses, and to compare values of this forces with their permissible values.

For the loading calculator, operating instructions shall always be provided.

The loading calculator together with the instructions are subject of PRS approval.

16 HULL FATIGUE STRENGTH

16.1 General

16.1.1 In the case of the hull structure made of steel with increased strength or structure considered non-typical, PRS may require preparation and submitting for review the analysis of fatique strength of selected nodes of the hull.

16.1.2 The fatigue strength analysis shall include the following hull structural members:
- connections of longitudinal stiffeners of side, bottom and decks plating with transverse frames and transverse bulkheads,
- brackets of longitudinal and transverse girders;
- the edges of openings and cut–outs in girders;
- strength deck cargo hatchway corners;
- strength deck brackets at the ends of longitudinal hatch coamings.

16.2 Method and Criteria of Fatique Life Analysis

16.2.1 Analysis of fatigue life shall be performed in accordance with the requirements of *Publication No 45/P – Fatigue Strength Analysis of Steel Hull Structure*.

Below, in 16.2.2. to 16.2.10, general principles of analysis, conforming with the applied in the above mentioned PRS *Publication,* are specified.

16.2.2 In the analysis of fatigue life, variable in time (pulse) stresses in a ship's hull structure caused by the forces of inertia from cargo, stores, equipment and construction of ship, generated in the ship's motions on the wave by the dynamic pressure of water, shall be taken into account.

16.2.3 Effects, on the fatigue life, of changing stresses arising from the structure vibration imposed by the ship propulsion system, auxiliary engines, machinery and equipment installed on the ship, as well as the stresses caused by the surge loads in the form of slamming and sloshing, shall be subject to separate consideration by PRS.

In the analysis of fatigue life, cycles of stress, in areas at risk of fatigue cracking, are taken into account. The essential is the value of stresses range, $\Delta\sigma$ (Fig. 16.2.3). corrected for the value of considered structural element plating thickness, and the average values of stress $\sigma_{śr}$ in the cycle.

$\Delta\sigma$ correction shall be performed in accordance with the requirements of the above mentioned *Publication No. 45/P*.

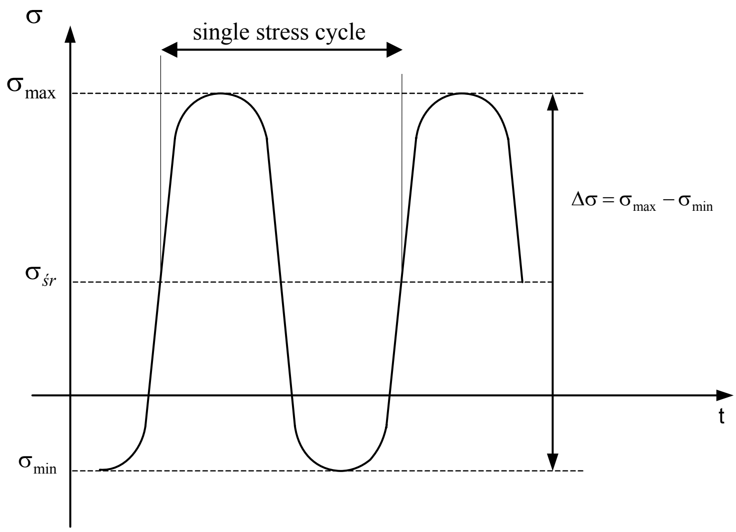


Fig. 16.2.3 Definition of stresses cycle and the range of stresses

16.2.4 Fatigue life analysis may be performed on the basis of nominal and geometrical values of stresses range.

Nominal stresses are calculated by material strength method, with application of rods or beams models.

Geometrical stresses are calculated by the use of FEM models, with application of special procedure of stresses values extrapolation.

Requirements concerning FEM models and stresses extrapolation are provided in the above mentioned *Publication No. 45/P*.

16.2.5 Dynamic loads (wave), applied for calculations of stresses mentioned in 16.2.4, shall be determined acc. to formulae provided in Chapters 15 and 17.

The above loads are applicable to ships of unrestricted service area.

Stresses range, $\Delta\sigma$, may, in general, be calculated as doubled value of stresses corresponding to wave loads.

It is assumed, that stresses range probability distribution is determined by Weibull's distribution:

$$\Pr(\Delta\sigma \geq \Delta\sigma_0) = e^{-\left(\frac{\Delta\sigma_0}{a}\right)^{\xi}} \qquad (16.2.5)$$

where:

$\Pr(\Delta\sigma \geq \Delta\sigma_0)$ – event probability, whilst $\Delta\sigma \geq \Delta\sigma_0$.

ξ – non-dimensional parameter; for calculations $\xi = 1.0$ may be taken;

$a = \dfrac{\Delta\sigma_R}{(ln\, N_R)^{1/\xi}}$

$\Delta\sigma_R$ – value of $\Delta\sigma$ exceeded with probability $\frac{1}{N_R}$; it is recommended to adopt $N_R = 10^4$ – as in *Publication No. 45/P*.

The way of $\Delta\sigma_R$ calculations in cases, where in the structure element superposition of stresses from general and local bending occurs, is defined in *Publication No. 45/P*.

16.2.6 In fatigue life analysis, adoption of the long term distribution of $\Delta\sigma$ determined directly with application of the hull's wave loads spectrum analysis, as well as statistic data concerning wave motions in sea areas foreseen for the ship's service, is recommended.

Detailed requirements for such calculations are provided in *Publication No. 45/P*.

16.2.7 Fatigue life calculations shall be performed with application of Wöhler's diagrams, specifying number of stresses cycles effecting with fatigue cracks, in function $\Delta\sigma$ = const.

The mode of Wöhler's diagrams selection for the structure elements of the ship's welded hulls, as well as the diagrams' correction in order to take into account the corrosive effect of sea water are provided in *Publication No. 45/P*.

16.2.8 The hull structure elements shall satisfy the following criterion:

$$D \le 1.0 \qquad (16.2.8)$$

where:

D – fatigue deterioration rate.

D – shall be calculated acc. to 16.2.9.

16.2.9 In D calculations, actual stresses cycles (random) finite number of stresses blocks I_p may be approximate $\Delta\sigma$ = const:

$$D = \sum_{i=1}^{I_p} \frac{n_i}{N_i} \qquad (16.2.9\text{-}1)$$

where:

N_i – number of stresses cycles determined from Wöhler's diagram for $\Delta\sigma_i$ = const ($\Delta\sigma_i$ – value $\Delta\sigma$ = const in "i" block),

n_i – number of stresses cycles in "i" block, determined from the formula:

$$n_i = p(\Delta\sigma_i)\,\delta\sigma_i N_L \qquad (16.2.9\text{-}2)$$

$p(\Delta\sigma_i)$ – value of long term distribution probability density function $\Delta\sigma$, for $\Delta\sigma = \Delta\sigma_i$;

$\delta\sigma_i$ – width of "i" block $\Delta\sigma$ (difference between extreme values $\Delta\sigma$ in "i" block);

N_L – number of stresses cycles during planned ship service, determined acc. to 16.2.10.

16.2.10 The number of stresses cycles during entire service of the ship shall be determined from the formula:

$$N_L = 3 \cdot 10^6 L_l c \qquad (16.2.10)$$

where:

L_l – planned period of the ship service, in years;

c – ratio of time at sea to assumed service time; for calculations $c \geq 0.5$ shall be adopted.

17 HULL LOADS

17.1 General

17.1.1 In the present chapter, principles for estimation of values for design local and general loads, acting on the ship's hull in wave conditions, as well as loads from wind and ice, are provided.
Mode of design loads on decks and bulkheads estimation is also provided.

17.1.2 The hull dynamic design loads, resultant from waves motion, may be determined by use of parametric formulae provided in 17.5 i 17.6, or by direct calculations, in accordance with principles provided in 17.2.

17.2 Wave Motions

17.2.1 General

17.2.1.1 In the case of ships with typical dimensional proportions and the hull shape ($L_0 / B \geq 5$, $B / H \leq 2.5$, $\delta \geq 0.6$), the design loads for ships of unrestricted service area, resulting from wave motions, shall be determined from formulae given in 17.5 and 17.6.

17.2.1.2 In the case of restricted service area, the loads determined in accordance with the requirement of 17.2.1.1 may be decreased in the following mode:
– for service area II by 10%,
– for service area III by 30%.

17.2.1.3 In the case of ships with dimensional proportions and other features recognized by PRS as non-typical, the direct calculations of the dynamic loads are required – in accordance with the principles of 17.2.2, or model tests – in accordance with principles of 17.2.3.

In the case of the ships of restricted service areas determined loads are subject of reduction – acc. to the requirements provided in 17.2.1.2, or direct calculations for actual waves motion in the restricted service shall be performed.

17.2.2 Direct Loads Calculations

17.2.2.1 Direct loads calculation is required in situations defined in 17.2.1.3, but it can also be applied for determination of dynamic design loads of the hull, associated with sailing of the ship on waves – in the place of the loads determined acc. to formulae provided in 17.5.2 i 17.5.3.

17.2.2.2 It is recommended to perform calculations acc. to algorithm presented in 17.2.2.4 to 17.2.2.10.

Alternative methods of calculations shall be separately considered by PRS.

17.2.2.3 Report on calculations containing following information shall be submitted to PRS:

- description of applied calculation method and computer programmes;
- calculations input data, including description of wave conditions, applied course angles and the ship's speed, the ship's weights distribution, etc.;
- comprehensive extract of the calculations results.

17.2.2.4 Direct calculations of the ship's hull response to wave motions may be performed by applying linear model and spectral analysis.
Such calculations include following stages:

a) determination of amplitudes transfer function of the ship response to the regular wave – e.g. the hull bending moment in the vertical plane, water pressure at any point of plating, etc. (17.2.2.5);
b) accomplishing short-term forecast for momentary extreme values of the response to the irregular wave (17.2.2.6 to 17.2.2.8);
c) accomplishing long-term forecast (17.2.2.9 and 17.2.2.10).

17.2.2.5 Calculations of amplitudes transfer function (see 17.2.2.4) consist in solving linear differential equations of motions of the ship with non-deformable hull, of unitary height wave, using the theory of potential flow of ideal fluids, and computer programs approved by PRS.

Amplitudes of the hull accelerations, dynamic pressures from water (from outside), internal forces in the hull, etc. are determined.

Calculations shall be performed for a number of circular wave frequency, ω, in the range from $0.5\left[\frac{\text{rad}}{s}\right]$ to $3.0\left[\frac{\text{rad}}{s}\right]$, for the ship's course angles μ in relation to the direction of variable waves, in steps not greater than 30° (μ = 0°, 30°, ..., 330°).

Note: m = 180°, when the ship moves in a di-rection opposite to the direction of the wave, perpendicularly to the wave crests.

For calculations, service speed shall be assumed.

17.2.2.6 Short-term forecast consists in the analysis of hull's response to determined irregular wave motion (actual), described by spectral density function.

Spectral density function of the hull response to waves motion (17.2.2.7), and then probability distribution of the momentary extreme values of response (17.2.2.8), used for accomplishment of the long-term forecast (17.2.2.9 and 17.2.2.10).

For the ships of unrestricted service area, the waves motion spectral density function shall be determined in the form of formula (for the North Atlantic region):

$$S(\omega,\mu,H_s,T_1)=\frac{2}{\pi}\,\frac{172H_s^2}{T_1^4\,\omega^5}\,\exp\left(-\frac{691}{T_1^4\omega^4}\right)\cos^2\mu \qquad (17.2.2.6)$$

where:

S – waves motion spectral density function,

ω – circular wave frequency, [rad/s],
μ – course angle (see 17.2.2.5), [degrees],
H_s – wave significant height, [m], (expected value of the waves heights of the accessible irregular waves motion, whose values are not less than the wave height exceeded with the probability of 1/3),
T_1 – characteristic wave period, [s].

For the ships intended for service in specific waters, the S value shall be determined on the basis of available literature data.

17.2.2.7 Spectral density function S_0 of the hull response to waves motion shall be determined from the formula:

$$S_0(\omega_E, \mu, H_s, T)_1 = |Y(\omega_E, \mu)|^2 \; S(\omega, \mu, H_s, T_1) \qquad (17.2.2.7\text{-}1)$$

where: ω_E – meeting frequency calculated from the formula:

$$\omega_E = \omega \left| 1 - \frac{\omega \upsilon}{g} \cos\mu \right|, \ \text{[rad/s]} \qquad (17.2.2.7\text{-}2)$$

v – speed of ship, [m/s],
g = 9.81 – acceleration of gravity, [m/s^2],
μ – the ship course angle (see 17.2.2.5),
S, ω, H_s, T_1 – see 17.2.2.6.

17.2.2.8 Probability of the event, that in the wave motion conditions specified by pa-rameters H_s and T_1 (see 17.2.2.6), and at the ship's course angle μ in relation to the direction the waves, the response parameter α (acceleration, dynamic pressure, etc.) exceeds the level of α_0 is defined by Rayleigh's distribution:

$$\Pr(\alpha \geq \alpha_0) = \exp\left(-\frac{\alpha_0^2}{2m_0} \right) \qquad (17.2.2.8\text{-}1)$$

where:

$$m_0 = \int_0^\infty S_0(\omega_E, \mu, H_s, T_1) d\omega_E \qquad (17.2.2.8\text{-}2)$$

S_0, ω_E, H_s, T_1 – see 17.2.2.7.

17.2.2.9 The long-term prediction shall be performed to determine the probability of an event $\Pr(\alpha \geq \alpha_0)$ that, during the entire service life of the ship (30 continuous years at sea), the response parameter α exceeds α_0 level.

$\Pr(\alpha \geq \alpha_0)$ may be determined from the following, approximate formula:

$$\Pr(\alpha \geq \alpha_0) = \sum_{i=1}^{N_H} \sum_{j=1}^{N_T} \sum_{k=1}^{N_k} \exp\left(-\frac{\alpha_0^2}{2m_0} \right) P_{ij} \, P_k \qquad (17.2.2.9)$$

where:
N_H – number of considered values of the significant waves height, H_s,

N_T – number of considered values of characteristic wave period, T_1,

N_k – number of considered values of the ship's course angles in relation to waves direction,

P_{ij} – probability of occurrence of wave motion conditions determined by value H_{si} of significant wave height, and value T_{1j} of characteristic period,

P_k – probability of course angle μ_k occurrence.

Notes:

1) It shall be assumed that the ship is submerged to the level of the design draft, and all angles of course angles in relation to the waves direction are equally probable, e.g. $P_k = 1/N_k$..
2) P_{ij} values shall be determined acc. to 17.2.2.10.
3) The formula 17.2.2.9 may be modified in a manner agreed with PRS, in order to take into account the reaction of captain in the form of changes in the course angle or reduction of the ship's speed, if such phenomena as slamming, excessive roll or emerging of propellers occur.

17.2.2.10 For the ships with unrestricted service area, in calculations acc. to formula 17.2.2.9 it is sufficient to apply H_{si}, T_{1j} and P_{ij} provided in Table 17.2.2.10.

Table 17.2.2.10
Probability of various sea states occurrence

H_s [m] \ T_2 [s]	1,75	2,85	3,95	4,91	5,72	6,50	7,31	8,27	9,30	10,22	11,15	12,21	13,49	15,09	17,11	19,38
26																
22															1,54E-5	1,52E-5
20														8,41E-6	1,54E-5	4,90E-5
18														5,05E-5	1,01E-4	9,31E-5
16													1,05E-4	2,20E-4	3,49E-4	9,91E-5
14												1,79E-4	4,17E-4	9,95E-4	4,21E-4	1,23E-4
12											4,29E-4	8,71E-4	2,12E-3	1,38E-3	3,10E-4	1,17E-4
10											4,36E-3	6,20E-3	3,61E-3	1,68E-3	4,97E-4	1,05E-4
9										7,09E-4	5,52E-3	3,73E-3	2,18E-3	8,15E-4	2,19E-4	4,98E-5
8									3,04E-4	3,34E-3	7,14E-3	4,61E-3	2,07E-3	7,57E-4	2,13E-4	5,11E-5
7									2,73E-3	9,11E-3	8,55E-3	4,43E-3	1,95E-3	7,00E-4	2,19E-4	5,11E-5
6								7,09E-4	1,69E-2	1,35E-3	8,40E-3	4,14E-3	1,76E-3	7,18E-4	2,20E-4	4,98E-5
5							3,04E-4	7,39E-3	3,57E-2	1,52E-2	7,53E-3	3,75E-3	1,80E-3	7,21E-4	2,13E-4	4,95E-5
4						3,04E-4	6,07E-3	3,64E-2	3,92E-2	1,55E-2	7,25E-3	3,84E-3	1,80E-3	7,00E-4	2,13E-4	4,72E-5
3					3,04E-4	8,81E-3	4,89E-2	4,32E-2	3,67E-2	1,44E-2	7,28E-3	3,75E-3	1,76E-3	6,83E-4	1,98E-4	4,60E-5
2				3,04E-4	2,02E-2	5,71E-2	5,19E-2	3,34E-2	2,53E-2	1,18E-2	6,96E-3	3,59E-3	1,63E-3	6,49E-3	1,98E-4	3,53E-5
1			1,32E-3	2,53E-2	5,09E-2	3,85E-2	2,94E-2	2,13E-2	2,10E-2	8,10E-3	5,92E-3	2,73E-3	1,112E-3	3,75E-5	7,25E-5	1,59E-5
0		2,02E-3	2,33E-3	2,10E-2	1,75E-2	1,45E-2	1,52E-2	9,52E-3	7,79E-3	3,04E-3	2,43E-3	1,27E-3	5,98E-4	2,38E-4	7,25E-5	1,69E-5
T_2 [s]	1,75	2,85	3,95	4,91	5,72	6,50	7,31	8,27	9,30	10,22	11,15	12,21	13,49	15,09	17,11	19,38

The following correlation between T_2 values used in the Table, and T_1 values takes effect:

$$T_1 = 1.086\,T_2 \quad (17.2.2.10)$$

Values P_{ij} in the Table 17.2.2.10 determine the probability of occurrence of various waves motion conditions in the region of the North Atlantic.

For the ships intended for service in specific waters, the P_{ij} values shall be determined on the basis of available statistics.

17.2.3 Model Tests

17.2.3.1 Model tests may be required in situations described in 17.2.1.3.

Before commencement of model tests, it is recommended to agree with PRS their scope and manner of conduct.

17.2.3.2 Documentation on model tests shall be submitted to PRS not later than at the time of delivery of the hull structural drawings for approval.

Following scope of documentation is required:

– data on model design and measuring equipment;
– description of the model basin and its measuring equipment;
– description of the mode for generating waves in the basin and measurement of wave motion parameters;
– results of measurements in the form of a table or diagram, and conversion of these results to the values relevant for the ship.

17.2.3.3 Execution of measurements of the model response to waves motion, in the following minimum scope, is required:

type of waves motion – regular and irregular waves motion;

course angles – 180° (model moves in the opposite to the waves direction, perpendicularly to the waves crests), 0°, 45° or 315°, 90°, 135° or 225°;

model speed – speeds corresponding to 0 (zero) speed, service speed and a half of service speed;

angular frequencies of the waves motion – at least six frequencies corresponding to waves lengths in the range from zero to 1.5 L_0.

17.2.3.4 Measurements of the following parameters of the ship's model response to waves motion, important in respect to the ship's hull strength shall be made:

– wave bending moments in vertical and horizontal planes, as well as wave torsional moment (for ships with wide openings in the upper deck), for

$$\frac{x}{L_0} = 0 \text{ and } \frac{x}{L_0} = \pm 0{,}25\,;$$

– vertical accelerations in region of midship and ship's ends;
– dynamic water pressures to the bottom and sides in the above regions;
– pressures from bottom and side slamming under typical, expected ship's draughts and speeds.

17.3 Wind

17.3.1 Consideration of loads from wind may be necessary for determination of impact on the ship's hull of the forces from the equipment elements, armament, etc attached to the hull.
Design values of these loads shall be determined for the wind velocity $V = 40$ m/s.

17.3.2 Forces charging the individual elements attached to the hull of the ship, due to the wind, shall be calculated from the formula:

$$F = 0.5\rho_p C_s C_H A V^2 \text{, [N]} \qquad (17.3.2)$$

where:
F – force acting on the element, [N];
ρ_p – air density, equal to 1.222 kg/m^3;
C_s – non-dimensional factor depending on elements' shape; C_s values for the most common shapes are provided in Table 17.3.2-1;
C_H – non-dimensional factor depending on the height above water level; C_H values are provided in Table 17.3.2-2;
A – area of element's projection at the plane perpendicular to the wind direction, [m^2];
V – wind velocity, [m/s].

Table 17.3.2-1
C_s Factor Values

Shape/kind of element	C_s
spherical	0.4
cylindrical	0.5
ropes	1.2
separated girders	1.3
small equipment elements	1.4
elevators, cranes	1.5
deckhouses	1.1

Tabela 17.3.2-2
C_H Factor Values

Height above water level, [m]	C_H
0 – 15.3	1.00
15.3 – 30.5	1.10
30.5 – 46.0	1.20
46.0 – 61.0	1.30

17.4 Ice

17.4.1 Ice Strengthening

Ships intended for service in sea areas, where ice cover or ice float may occur shall have the hull adequately strengthened – in accordance with the requirements of Chapter C/11.

17.4.2 Ship Icing

17.4.2.1 In relation to ships intended for periodical service in Arctic or Antarctic areas, PRS may require, that the strength criteria provided in the present part of the *Rules,* for the loads increased by the loads from expected icing of the above-water body, with values provided in 17.4.2.2., shall be satisfied.

17.4.2.2 In the hull longitudinal strength analysis acc. to requirements of Chapter 15, local strength analysis acc. to Chapter 13 and zone strength analyzis acc. to 14, for ships endangered by icing, loads on external surfaces of the above-water part of the hull from ice layer, additional to the required standard loads, shall be taken into account with the following values:

– pressure 1 kPa (ice layer of 100 mm thickness) acting on horizontal, or close to horizontal, surfaces,
– vertical load 0.25 kN/m^2 (ice layer of 25 mm thickness) acting on vertical, or close to vertical, surfaces.

17.5 Ship Motions

17.5.1 General

17.5.1.1 The present Chapter gives formulae for determining motions (displacements, velocities and accelerations) of ships in sea-going conditions during their normal service.

17.5.1.2 The ship motions determined in present Chapter are the values for which probability of exceeding is 10^{-8}.

17.5.2 Definitions

17.5.2.1 Co-ordinate System

The co-ordinate system, as well as names of various ship motions, assumed in this Chapter, are defined in Fig. 17.5.2.1.

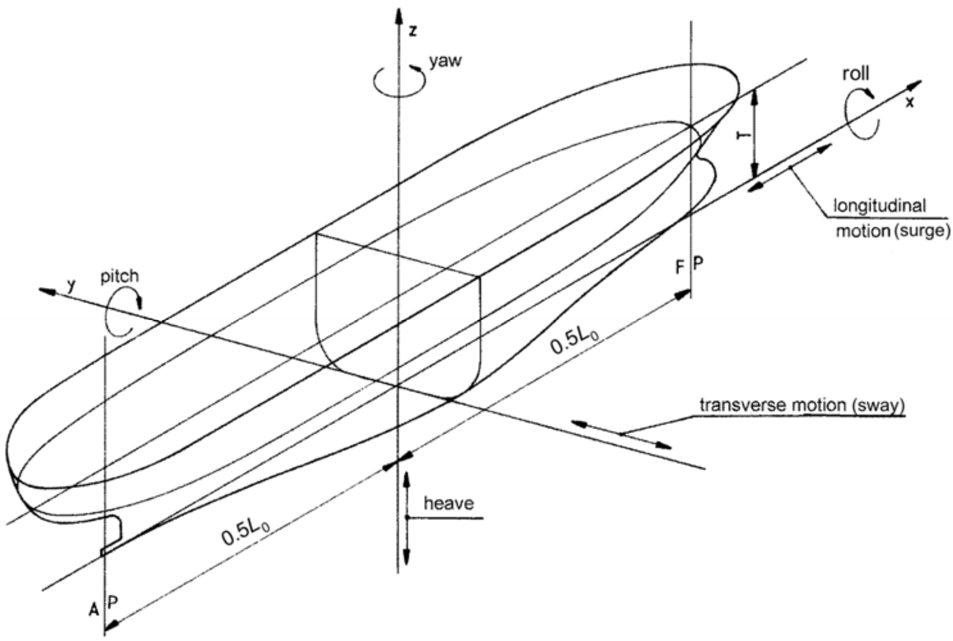


Fig. 17.5.2.1 Definition of Co-ordinate System and Ship motions

17.5.2.2 Wave Coefficient

The wave coefficient C_w, which is the basic parameter for determining wave induced hull loads and ship motions, shall be determined in accordance with the following formula:

$C_w = 0.0792 L_0$ for $L_0 \le 100$ m,

$$C_w = 10.75 - \left(\frac{300 - L_0}{100}\right)^{3/2} \quad \text{for} \quad 100 \text{ m} < L_0 < 300 \text{ m}, \qquad (17.5.2.2)$$

17.5.3 Amplitudes of Ship Motions

17.5.3.1 Heave Amplitude

The heave amplitude may be determined in accordance with the following formula:

$$Z_A = 12 - 0.1T \quad [\text{m}] \qquad (17.5.3.1)$$

T – see sub-chapter 1.2.2.

17.5.3.2 Pitch Amplitude

The pitch amplitude may be determined in accordance with the following formula:

$$\Theta_A = 4\left(1 - 4.5\frac{T}{L_0}\right)\frac{C_w}{L_0} \quad [\text{rad}] \qquad (17.5.3.2)$$

17.5.3.3 Roll Amplitude

The roll amplitude may be determined in accordance with the following formula:

$$\Phi_A = 35\frac{T}{B^2+50} \quad \text{[rad]} \qquad (17.5.3.3)$$

17.5.3.4 Surge Amplitude

The surge amplitude may be determined in accordance with the following formula:

$$X_A = 8\frac{1-0.03T}{1-0.036v} \quad \text{[m]} \qquad (17.5.3.4)$$

v – ship speed, [knots].

17.5.3.5 Sway Amplitude

The sway amplitude may be determined in accordance with the following formula:

$$Y_A = 12 - 0.25T \quad \text{[m]}. \qquad (17.5.3.5)$$

17.5.3.6 Yaw Amplitude

The yaw amplitude may be determined in accordance with the following formula:

$$\Psi_A = 0.25\left(1-0.008\frac{L_0}{B}\right) \quad \text{[rad]}. \qquad (17.5.3.6)$$

17.5.3.7 Relative Motion Amplitude

Motion amplitude of ship's point P (x, y, z) in relation to the wave surface may be determined in accordance with the following formula:

$$S_A = \sqrt{(0.3Z_A)^2 + \left[(x+0.05L_0)\Theta_A\right]^2 + \left[0.8\,y\,\Phi_A\right]^2} \quad \text{[m]} \qquad (17.5.3.7)$$

Z_A, Θ_A, Φ_A – see sub-chapters 17.5.3.1, 17.5.3.2 and 17.5.3.3;
x, y – co-ordinates of P point – see Fig. 17.5.2.1.

17.5.4 Resultant Acceleration Amplitudes

17.5.4.1 Resultant Vertical Acceleration

The resultant linear acceleration of the ship's point P along the vertical axis (taking no account of gravity acceleration) shall be determined in accordance with the following formula:

$$a_v = (1+0.036v)^2\frac{25}{L_0}\sqrt{Z_A^2 + \left[1.6(x+0.05L_0)\Theta_A\right]^2 + \left[0.5y\Phi_A\right]^2} \quad \text{[m/s}^2\text{]} \qquad (17.5.4.1)$$

v – ship service speed, [knots];

Z_A, Θ_A, Φ_A – see sub-chapters 17.5.3.1, 17.5.3.2 and 17.5.3.3;
x, y – co-ordinates of P point – see Fig. 17.5.2.1.

17.5.4.2 Resultant Transverse Acceleration

The resultant linear acceleration of the ship's point P along the transverse axis (taking into account gravity acceleration) shall be determined in accordance with the following formula:

$$a_T = (1 + 0.036v)^2 \frac{25}{L_0} \sqrt{(0.8Y_A)^2 + [(x + 0.05L_0)\Psi_A]^2 + [(z - T)\Phi_A]^2} \quad [\text{m/s}^2] \qquad (17.5.4.2)$$

v – ship service speed, [knots];
Θ_A, Y_A, Ψ_A – see sub-chapters 17.5.3.2, 17.5.3.5 and 17.5.3.6;
x, z – co-ordinates of P point – see Fig. 17.5.2.1.

17.5.4.3 Resultant Longitudinal Acceleration

The resultant linear acceleration of the ship's point P along the longitudinal axis (taking into account gravity acceleration) shall be determined in accordance with the following formula:

$$a_L = (1 + 0.036v)^2 \frac{25}{L_0} \sqrt{(0.2X_A)^2 + [0.5y\Psi_A]^2 + [2(z - T)\Theta_A]^2} \quad [\text{m/s}^2] \quad (17.5.4.3)$$

v – ship service speed, [knots];
Θ_A, X_A, Ψ_A – see sub-chapters 17.5.3.2, 17.5.3.4 and 17.5.3.6;
y, z – co-ordinates of P point – see Fig. 17.5.2.1.

17.5.4.4 Resultant Acceleration in any Direction

The resultant linear acceleration of the ship's point P in any direction may be determined from ellipsoid (Fig. 17.5.4.4) with principal axes ($a_v + g$), a_T and a_L.

a_v, a_T and a_L – see sub-chapters 17.5.4.1, 17.5.4.2 and 17.5.4.3.

P (x, y, z) – point for which the accelerations are determined.

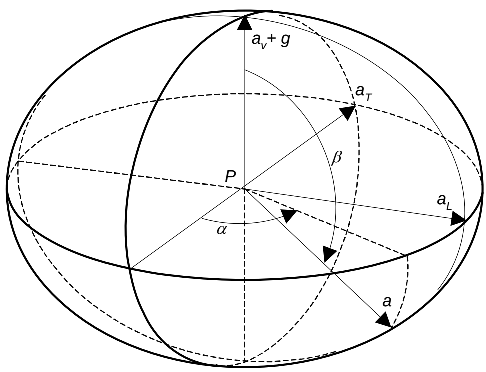


Fig. 17.5.4.4 Determining acceleration a of the ship's point P in any direction

17.6 Local Loads on Structure

17.6.1 General

17.6.1.1 The design load values determined according to the indications given below are applicable for scantling of side shell plates, stiffeners, ordinary girders, complex girders systems and a support-type members included in the individual construction of the hull. These are design values, which may be applied only under the ap-proach taken to requirements concept.

17.6.1.2 For determination of design loads on the structure, static and dynamic components of the load caused by:
– impact of the sea (see 17.6.3, 17.6.4),
– impact of liquids in tanks (see 17.6.5),
– impact of dry cargoes, stores, equipment and armament (see 17.6.7).
are taken into account

17.6.1.3 In general, the loads from both sides may act on considered side plating and its supporting members. They shall be determined independently and, as a design loads, the greater values shall be taken. In particular cases, if both loads are always acting simultaneously, their difference may be assumed as a design load.

17.6.1.4 Tanks serving for fuel or lubricating oil carriage shall be calculated for liquid with density equal to sea water density:

$$\rho = 1.025 \text{ t/m}^3.$$

17.6.1.5 Structure of tanks for the carriage of liquids with greater density are subject to separate PRS consideration.

17.6.2 Descriptions

b_a – the greatest lateral distance, measured parallel to the y axis, from the point of the resultant load application, to the upper corner of the tank the most remote from this point, [m];
b_s – tank top width, [m];
b_z – the distance, measured parallel to the y axis, between side bulkheads of the tank, or longitudinal sloshing bulkheads, at the height of considered point of the resultant load application, [m];
g – gravity acceleration, [m/s^2]; shall be assumed $g = 9.81$ m/s^2;
h_a – vertical distance measured from the point of the resultant load application to the tank top or the hatch coaming, [m]; for high, narrow tanks h_a value may be assumed as not greater than 15 times the smallest width (or length) of the tank measured above the point of the load resultant application;
h_g – vertical distance measured from the point of load application to the bulkhead top, [m].
Application of lower value of h_g, confirmed by the ship's subdivision analysis, is permitted;

h_p – vertical distance measured from the point of resultant load application to the upper end of the air-pipe, [m];
h_0 – vertical distance measured from the waterline corresponding to the ship full displacement to the point of resultant load application, [m];
h_z – height of the tank, [m];
l_a – the greatest longitudinal distance, measured parallel to x axis from the point of the resultant load application, to the upper corner of the tank the most remote from this point, [m];
l_s – length of the tank top, [m];
l_z – the distance, measured parallel to x axis, between transverse tight or sloshing bulkheads at the height of the considered structure element, [m];
p_0 = 15 kPa, but assumed p_0 value shall not be less than p_v pressure;
p_v – pressure, at which the safety valve gets open, [kPa];
T_m – minimum service draught of the ship, [m]; T_m value shall, in general, be assumed as equal to $0.35T$;
ρ – cargo, ballast or stores density, [t/m^3];
P (x, y, z) – point in the ship, in which the pressure from the sea impact is determined;
p_i – pressure from the sea impact in point P, i = 1,....5, [kPa].

17.6.3 The Ship Hull External Pressure

17.6.3.1 In the point *P(x, y, z),* pertaining to the ship's side below the design waterline, or pertaining to the bottom, external pressure from the sea impact shall be determined from the formula:

$$p_1 = 0.5 p_{db} + 10(T - z), \quad \text{[kPa]} \qquad (17.6.3.1\text{-}1)$$

$$p_{db} = (1 + 0.036v)\left[0.7Z_A + k_x\theta_A + 3|y|\Phi_A\right] + 0.02L_0 \times \left[10 - 0.25(T - z)\right], \text{[kPa]} \qquad (17.6.3.1\text{-}2)$$

$$k_x = \begin{cases} -4(x + 0.05L_0) & \text{dla} \quad x < -0.05L_0 \\ 5.4(x + 0.05L_0) & \text{dla} \quad x \geq -0.05L_0 \end{cases} \qquad (17.6.3.1\text{-}3)$$

v – service speed of the ship, [knots];
Z_A, Θ_A, Φ_A – see 17.5.3.1 to 17.5.3.3;
x, y, z – point $P(x, y, z)$ co-ordinates – see Fig. 17.5.2.1.

17.6.3.2 In point $P(x, y, z)$, pertaining to the side at the level of unsheltered deck, pressure from the sea impact shall be determined from the formula:

$$p_2 = 0.5\, p_{ds}, \quad \text{[kPa]} \qquad (17.6.3.2\text{-}1)$$

$$p_{ds} = \rho g\,[S_A - (z - T)], \quad \text{[kPa]} \qquad (17.6.3.2\text{-}2)$$

ρ = 1.025 t/m^3;
whilst it shall be assumed, that: $[S_A - (z - T)] \geq 2$;
S_A – see 17.5.3.7;
$z - T$ – the distance between the design waterline and P point.

17.6.3.3 Between the deck and the design waterline, the pressure shall be determined by the linear interpolation. In the end parts of the ship the pressure is determined by the formulae 17.6.3.1-1 and 17.6.3.1-2.

17.6.3.4 In the point $P(x, y, z)$, pertaining to the unsheltered deck, the external pressure from the sea impact shall be determined from the formula:

$$p_3 = 0.5 p_{dd}, \quad \text{[kPa]} \qquad (17.6.3.4\text{-}1)$$

$$p_{dd} = 0.5\rho\,(g + 0.5a_v)\,[S_A - (z - T)], \quad \text{[kPa]} \qquad (17.6.3.4\text{-}2)$$

whilst it shall be assumed, that: $[S_A - (z - T)] \geq 2$;
S_A and a_v – see 17.5.3.7 i 17.5.4.1;
ρ = 1.025 t/m^3.

17.6.3.5 External pressure acting on the ship's bottom and sides, which may be deducted from internal pressures in the tanks adjacent to these structures, corresponds to the ship's minimum still water service draught. Its value shall be determined from the formula:

$$p = \rho g \left(T_m - z\right), \quad \text{[kPa]} \qquad (17.6.3.5)$$

whilst p shall be ≥ 0;
ρ = 1.025 t/m^3;
z – co-ordinate of the point under consideration.

17.6.4 External Pressures Acting on Superstructures

17.6.4.1 Induced by the marine environment external pressures acting on unsheltered walls of superstructures and deckhouses (engine casings) may be determined acc. to formulae provided in 17.6.4.2 and 17.6.4.3.

17.6.4.2 In the point *P(x, y, z)* pertaining to unsheltered front wall of the superstructures or deckhouses:

$$p_4 = 3 p_{dd}, \quad \text{[kPa]} \qquad (17.6.4.2)$$

whilst it shall be assumed, that: $[S_A - (z - T)] \geq 1$;
p_{dd} – see 17.6.3.4.

17.6.4.3 In the point $P(x, y, z)$ pertaining to unsheltered side and aft walls of the superstructures or deckhouses:

$$p_5 = 0.5 p_{ds}, \quad \text{[kPa]} \qquad (17.6.4.3)$$

whilst it shall be assumed, that: $[S_A - (z - T)] \geq 1$;
S_A – see 17.5.3.7;
z – co-ordinate of the point under consideration;
p_{ds} – see 17.6.3.2.

17.6.5 Pressure in Emergency Cases

17.6.5.1 Design pressure for the watertight bulkhead (after compartment flooding) shall be determined from the formula:

$$p_{d1} = \rho g h_g , \quad \text{[kPa]} \qquad (17.6.5.1)$$

ρ = 1.025 t/m^3;

17.6.5.2 Design pressure for inner bottom after flooding of the double bottom shall not be assumed less than the pressure determined from the formula:

$$p_{d2} = \rho g T , \quad \text{[kPa]} \qquad (17.6.5.2)$$

ρ = 1.025 t/m^3;

This pressure is also a minimum pressure for scantling watertight floors and longitudinals, constituting boundaries of the double bottom tanks..

17.6.6 Liquid Pressure in Tanks

17.6.6.1 General

If the tanks designated for carriage of liquids may be full or empty, then design pressures acting on particular structures bordering these tanks shall be determined acc. to 17.6.6.2. Tanks bordering structures are: inner and outer bottom structures, sides, bilge, decks, platforms, tight walls (bulkheads) of the tanks in any spatial location. These structures may constitute common divisions of two adjacent tanks, and in such case they shall be considered as a separate border of each tank.

17.6.6.2 Liquid Pressure in Fully Filled Tanks

As a design pressures for structures bordering full filled tanks, the greatest pressure from $p_6 \div p_{10}$, determined from the following formulae shall be assumed:

$$p_6 = (g + 0.5 a_v) \rho h_a , \quad \text{[kPa]} \qquad (17.6.6.2\text{-}1)$$

$$p_7 = 0.67 \rho g h_p , \quad \text{[kPa]} \qquad (17.6.6.2\text{-}2)$$

$$p_8 = g \rho h_a + p_0 , \quad \text{[kPa]} \qquad (17.6.6.2\text{-}3)$$

$$p_9 = g\rho \left[0.67 \left(h_a + \Theta_A l_a \right) - 0.12 \sqrt{h_z l_s \Theta_A} \right] , \quad \text{[kPa]} \qquad (17.6.6.2\text{-}4)$$

$$p_{10} = g\rho \left[0.67 \left(h_a + \Phi_A b_a \right) - 0.12 \sqrt{h_z b_s \Phi_A} \right] , \quad \text{[kPa]} \qquad (17.6.6.2\text{-}5)$$

a_v – acc. to 17.5.4.1;
Φ_A – acc. to 17.5.3.3;
Θ_A – acc. to 17.5.3.2.

Formulae 17.6.6.2-4 i 17.6.6.2-5 shall be taken into account at scantling structures bordering cargo tanks, tanks for stores and ballast tanks, if the tank length exceeds $0.15L_0$, or the greatest tank width exceeds $0.4B$.

17.6.6.3 Liquid Pressure in Partially Filled Tanks

If the tanks, during the voyage, may be filled partially, in range of 20 to 90% of their height, then the design pressure (for tanks with parameters $l_z \le 0.13\ L_0$ and $b_z \le 0.56B$) shall be determined as the greater from the values of the pressure determined for the tank fully filled, acc. to 17.6.6.2, and, respectively, the value not less than determined from the formulae:

– for the structure elements located less than $0.25l_z$ from the tank transverse end bulkheads:

$$p_{11} = \rho\left(4 - 0.005L_0\right)l_z, \quad \text{[kPa]} \qquad (17.6.6.3\text{-}1)$$

– for the structure elements located less than $0.25l_z$ from the tank longitudinal bulkheads:

$$p_{12} = \rho\left(3 - 0.01B\right)b_z, \quad \text{[kPa]} \qquad (17.6.6.3\text{-}2)$$

For the tanks with parameters $l_z > 0.13\ L_0$ or $b_z > 0.56\ B$ values of pressures p_{11} or p_{12} are subject of separate PRS consideration. In relation to ships with length $50\ \text{m} \le L_0 < 100\ \text{m}$, separate consideration by PRS is provided in case of pressure p_{11}, when $l_z > 0.2\ L_0$.

17.6.6.4 Design pressure value assumed for girders' webs in cargo tanks, storage tanks and ballast tanks shall not be less than 20 kPa.

17.6.6.5 Design pressure of transverse and longitudinal sloshing bulkheads shall not be less than the pressure determined from the formulae 17.6.6.3-1 and 17.6.6.3-2.

17.6.6.6 Structures of sides, decks, longitudinal and transverse bulkheads which constitute tank boundaries are subject to checking the impact of the pressure p_{11}, in the ships with the length of $L_0 \ge 50$ m and also the impact of the pressure p_{12}, in the ships with the length $L_0 \ge 100$ m, in the given region, if such checking is required in the considered case.

17.6.7 Loads from Cargo, Stores and Equipment

17.6.7.1 Pressure acting on the ship's decks and bottom in cargo or storage compartments, originated from general cargo, stores or equipment shall be determined from the formula:

$$p_{13} = \left(g + 0.5a_v\right)q, \quad \text{[kPa]} \qquad (17.6.7.1)$$

where:

a_v – acc. to 17.5.4.1,

q = ρh – the weight of cargo or equipment, [t], related to 1 m^2 of the loaded surface,

ρ – density of the cargo charging the surface of the ship's deck or bottom, [t/m^3],

h – height of cargo or stores tier charging the surface of the ship's deck or bottom, [m]. The height h shall be measured vertically from the loaded surface to the deck above and to the upper edge of the hatch coaming within a cargo hatch.

It is recommended that assumed ρ value is not less than 0.7 t/m^3. Permissible q value may also be assumed directly by the ship designer and given in the loading manual.

17.6.7.2 For the sheltered, non-cargo decks, minimum q values are following:
q = 1.6 t/m^2 – for platforms in the engine room, (lesser values may be applied if they result from the weight of the ship's equipment elements provided for locating on the platform),
q = 0.35 t/m^2 – for the decks in the crew accommodations.

17.6.7.3 If the tare weight of the deck or platform structure exceeds 10% of the value of q from the weight of cargo, stores or equipment, it shall be included as a component of the load, by adequately increasing value of q, adopted for the strength calculations.

17.6.7.4 If the open deck is designated for the carriage of deck cargo, then as a design pressure value for such deck $p = p_2$ (see 17.6.3.2) or $p = p_{13}$ (see17.6.7.1) shall be assumed, depending on that whichever is greater.

If, on the open deck, the height of loading is less than 2.3 m, summation of loads from cargo and partial loads of sea effect may be required.

17.6.7.5 Minimum q value for open cargo decks is 1.0 t/m^2.

17.6.7.6 In the ships with restricted service area, $p = p_{13}$, determined acc. to formula 17.6.7.1 for cargo sheltered decks, platforms in the engine room, decks in compartments and the open deck designated for the carriage of deck cargo, may be reduced in accordance with indications provided in 17.2.1.2.

17.6.7.7 If the lateral forces acting on the deck from the cargo need to be known (for example for scantling determination of transverse supports of the hatch covers), they may be determined in the same way as for the calculation of the impact of heavy pieces of cargo or equipment, e.g. acc. to 17.6.8.

17.6.8 Loads from Heavy Pieces of Cargo, Equipment and Armament

Components of the forces affecting the supporting structures and the system for lashing of heavy pieces of cargo, equipment, armament or stores shall be determined by the formulae:

- the vertical force acting alone or in combination with the longitudinal force, determined from the formula 17.6.8-4:

$$P_v = (g + 0.5a_v)M\,, \quad \text{[kN]} \qquad (17.6.8\text{-}1)$$

- the vertical force considered together with the simultaneously acting transverse force, determined from the formula 17.6.8-3:

$$P_{vt} = gM\,, \quad \text{[kN]} \qquad (17.6.8\text{-}2)$$

– the transverse force considered together with the simultaneously acting vertical force, determined from the formula 17.6.8-2:

$$P_t = 0.67 a_T M\,, \quad \text{[kN]} \qquad (17.6.8\text{-}3)$$

– the longitudinal force considered together with the simultaneously acting vertical force, determined from the formula 17.6.8-1:

$$P_l = 0.67 a_L M\,, \quad \text{[kN]} \qquad (17.6.8\text{-}4)$$

M – mass of the considered element, [t];
a_v – vertical acceleration, [m/s^2], determined acc. to 17.5.4.1;
a_T – transverse acceleration, [m/s^2], determined acc. to 17.5.4.2;
a_L – longitudinal acceleration, [m/s^2], determined acc. to 17.5.4.3.

C ADDITIONAL REQUIREMENTS RELATED TO THE TASKS OF THE SHIP AND SPECIAL REQUIREMENTS

18 GENERAL PRINCIPLES

18.1 General Requirements

18.1.1 *Part C* contains additional requirements related to combat functions of the ship, and special requirements related to the hull ice strengthening.

18.1.2 Requirements for the ship's resistance to the action of the potential hazards of combat conditions are determined by the Purchaser in the tactical-technical requirements.

Requirements of defined ship's resistance may relate to the following issues:
– above-water explosion,
– on-water explosion,
– stroke from an underwater explosion,
– an internal explosion,
– the general vibration of the hull / whipping,
– the impact of splinters and shells of small arms
– survival of the ship in terms of significant damage to the hull,
– use of weapons of mass destruction (NBC).

18.1.3 Part C sets out how to set the loads of combat actions. Parameters of an explosive charge and the force resulting from the operation of its own weapons (e.g. guns, launchers) are in each case specified by the Purchaser.

The size and distribution of cargo or stocks and the load of cargo handling appliances are in each case determined by the Purchaser.

18.2 Required Documentation

18.2.1 Documentation demonstrating, how the established requirements relating to the ship resistance against impact of specified risks, as well as PRS requirements relating to the ship's tasks, are met, shall be submitted for PRS consideration.

Where PRS requires that direct calculations are to be made, information on computation programme, assumptions and computation data (including loads), calculation model and calculations results, shall be submitted.

In the case of model tests, performed for calculation verification, description of model and applied test equipment, information on loads, mode of their distribution and the test result shall be submitted to PRS.

18.2.2 Calculations and structural drawings, confirming that resistance requirements in relation to issues specified in. 1.1.2 shall be submitted.

18.2.3 Drawings of layout and structural details, as well as assumed loads shall be submitted for:

- structural reinforcements of the landing ships' bottom,
- helicopters landing grounds (helidecks),
- vehicle transportation decks,
- reinforcements in area of the guns and launchers foundations,
- reinforcements in area of sonar station casing,
- reinforcements in area of cargo handling appliances,
- masts,
- other specific structures depending on the ship's type.

18.2.4 Ice strengthening shall be demonstrated on the hull structural regions drawings, where applied.

18.3 Materials and Welding

18.3.1 The ships, which are to comply with the requirements for the resistance against specific risks, shall comply with the following requirements relating to application of welding consumables in appointed regions.

The requirements are applicable to plates, stiffeners, foundations, welded connections in specified below areas, unless provided otherwise.

In the case of the resistance against:

Table 1.3.1

Kind of the ship resistance provided	Regions of the hull, to which the above requirements apply
Over-water and on-water explosion	Over water part of the hull and superstructures, upper decks
Impact from underwater explosion	The hull shell plating
Internal explosion	Transverse and longitudinal bulkheads included in protective structure
The hull general vibrations/whipping	Deck stringer, sheer strake, bilge plate, keel and keel adjusting strake

18.3.2 In region $-0.3L < x < 0.3L$, the crack stopping strakes, made of grade E steel, shall be applied.

Where the resistance against impact from underwater explosion is required, the above strakes include deck stringer, sheer strake, bilge plating, keel and keel adjusting strake.

Where the resistance against general vibrations/whipping is required, the above strakes include deck stringer, sheer strake, bilge plating, keel and keel adjusting strake.

If the hull plating is entirely made of steel grade D, the range of steel grade E application shall be separately considered by PRS.

18.3.3 For welding of structural elements made of different grades of steel (A, B, D, E), welding consumables appropriate for higher grade of steel shall be applied.

18.3.4 For welding of structural elements made of steel with different strength, welding consumables appropriate for lower grade of steel may be applied.

18.3.5 Depending on the strength and the grade of steel, welding consumables, in compliance with the requirements specified in a Table 1.3.5, shall be applied.

Tabela 1.3.5
Welding consumables

Steel grade	Normally applied welding consumables	Welding consumables for welding of structures listed in. 1.3.1, 1.3.2
A	1	1
AH32	1Y	2Y
AH36	1Y	2Y
AH40	2Y40	2Y40
B	2	2
D	2	3
DH32	2Y	3Y
DH36	2Y	3Y
DH40	3Y40	3Y40
E	3	4
EH32	3Y	4Y
EH36	3Y	4Y
EH40	4Y40	4Y40

2 HULL RESISTANCE AGAINST DAMAGES

2.1 General

Limitation of the destruction zone, in effect of operation of the combat means with assumed parameters, shall be achieved by the proper division of the hull by transverse and longitudinal bulkheads, as well as decks of relevant strength.

To ensure general strength in damaged condition, application of longitudinal box girders in the hull structure, located on the left and right side in the deck region, as well as proper structure of the longitudinal bottom grid (box keel, etc.), is recommended.

2.2 Optimization of the Hull Subdivision

For optimization of the hull subdivision, performance of analysis in accordance with the guidelines contained in documents such as the NATO ANEP 43 "Ship Combat Survivability" is recommended. Mode to improve the ship resistance to damage shall be analysed for the emergency conditions at the following levels:

- provision of the buoyancy,
- provision of the ability to movements,
- provision of the combat abilities.

3 REQUIREMENTS RELATING TO THE DEFENSE AGAINST THE WEAPONS OF MASS DESTRUCTION

3.1 General

The effects of weapons of mass destruction (NBC) shall be prevented by creating a ship closed and autonomous zones or shelters to protect people from the consequences of its impact.

Relevant requirements are specified in sub-chapter 3.3. The Purchaser may change their scope of application depending on a type and size of the ship.

It is recommended when making decision on location of zones, and the hull structure bounding these zones, to take into account results of analysis on the improvement of the hull resistance to damage (see sub-chapter 2.2).

3.2 Descriptions

For the purpose of the Chapter 3, following additional descriptions are introduced:

Citadel – gas-tight region of the hull, bounded by the deck plating and walls and decks of the superstructures, containing inside group of gas-tight zones.

The citadel is provided with independent systems necessary for creation of a space free of threats caused by the NBC weapons.

Zone – gas-tight group of compartments inside the citadel, provided with a part or all independent systems necessary for creation of a space free of threats caused by the NBC weapons. It is required that each zone shall be provided with an independent ventilation/air-condition system provided with NBC filters.

The zones boundaries shall coincide with the transverse watertight bulkheads, and extend from the keel to the uppermost deck of the superstructure or the deckhouse.

Shelter – the separated gas-tight compartment(s) on the ship, provided with an air-lock, special procedures point and the vent-filtering system.

Air-lock – the vestibule for entering/leaving the gas-tight compartments, including special procedures points.

3.3 General Design Requirements for the Defense Against the Mass Destruction Weapons

3.3.1 Separation of the citadel and its division into zones is recommended for the relatively big ships. Necessity of the compliance with that requirement for the given ship is determined by the Purchaser.

3.3.2 The citadel shall be divided into at least four zones, each with the length of not more than 30 m. Total legth of two adjacent zones should not be less than $0.3L_w$, but not more than $0.5L_w$. The Purchaser may, however, describe other division into zones.

3.3.3 Each zone shall be provided with at least two air-locks, accessible from the open deck. Passages between the zones shall also be provided with the air-locks.

3.3.4 Ventilation ducts and cases shall not pass through the bulkheads constituting zones' borders.

3.3.5 In the ships, on which zones are not applied, shelters shall be provided.

3.3.6 Compartments adequately insulated, located deep inside the hull, giving the crew a shelter against radiation during the nuclear attack, shall be provided. The entire essential equipment of such compartments shall be resistant to radiation and the electro-magnetic impulse.

3.3.7 Materials applied for the ship's structure and equipment shall not emit toxic gases and secondary radiation..

3.3.8 All compartments and the equipment outside the citadel shall be so designed and sealed, that after deactivation procedures gathering of residual contamination in openings, niches, etc., shall not occur.

3.3.9 Service and maintenance of the deck equipment by the personnel wearing personal protection means shall be possible.

3.4 Requirements Relating to Gas-tight Structures Strength

3.4.1 Gas-tight structures, irrespective of compliance with the requirements contained in the Part B and the present Chapter, where applicable, shall withstand the action of the pressure equal to double value of the difference of air pressure on both sides of the shell plating, which may occur during the service.

3.4.2 All openings in the gas-tight structures shall be provided with the gas-tight closing appliances with the strength equal to the strength of the structure, in which they are placed. The closing appliances shall comply with the relevant requirements of the *Part III – Hull Equipment*.

4 LOADS FROM EXPLOSIONS AND THE STRUCTURE RESPONSE

4.1 General

The present Chapter 4 applies to ships, for which the Purchaser set demands for resistance against explosion of specified explosive charge in air, underwater and inside the ship (sub-chapter 4.2, 4.3, 4.4), or the resistance against the impact of splinters and shells of small arms (sub-chapter 4.5).

4.2 Air Explosion

4.2.1 General

4.2.1.1 Provisions of the present sub-chapter 4.2 are applicable for estimation of, caused by the air explosion, shock wave parameters and its impact to the ship.

4.2.1.2 Shock wave parameters are calculated for the spherical charges, which explosion power is defined by TNT equivalent. Radius of explosion shall be determined from the formula:

$$r_0 = 0.052\sqrt[3]{G}\ , \ \text{[m]} \qquad (4.2.1.2)$$

G – mass of TNT charge (TNT equivalent), [kg].

4.2.1.3 With respect to altitude of explosion the following explosions are distinguished:

.1 above-water explosion (air explosion) – when:

$$H \geq 0.35\sqrt[3]{G}\ , \ \text{[m]} \qquad (4.2.1.3\text{-}1)$$

.2 on-water explosion – when:

$$H < 0.35\sqrt[3]{G}\ , \ \text{[m]} \qquad (4.2.1.3\text{-}2)$$

H – explosion altitude above the sea level (terrain), [m];
G – mass of TNT charge (TNT equivalent), [kg].

4.2.2 Parameters of Shock Wave

4.2.2.1 Maximum pressure of the shock wave shall be determined from the following formulae:

– for the above-water explosion (air explosion):

$$\Delta p_m = 98\left[0.84\frac{\sqrt[3]{G}}{R} + 2.7\left(\frac{\sqrt[3]{G}}{R}\right)^2 + 7\left(\frac{\sqrt[3]{G}}{R}\right)^3\right], \ \text{[kPa]} \qquad (4.2.2.1\text{-}1)$$

– for the on-water explosion:

$$\Delta p_m = 98\left[1.06\frac{\sqrt[3]{G}}{R} + 4.3\left(\frac{\sqrt[3]{G}}{R}\right)^2 + 14\left(\frac{\sqrt[3]{G}}{R}\right)^3\right], \text{ [kPa]} \qquad (4.2.2.1\text{-}2)$$

G – mass of TNT charge (TNT equivalent), [kg];
R – distance from the center of charge, [m].

4.2.2.2 Endurance of the shock wave overpressure phase shall be determined from thee formula:

$$\tau_+ = 0.0015\sqrt[6]{G}\sqrt{R}, \text{ [s]} \qquad (4.2.2.2)$$

G – mass of TNT concentrated charge (TNT equivalent), [kg];
R – distance from the center of charge, [m].

4.2.2.3 Course of the overpressure in an air shock wave, in time interval $\langle 0;\tau_+\rangle$, shall be determined from the formula:

$$\Delta p(t) = \Delta p_m\left(1 - \frac{t}{\tau_+}\right)^n, \text{ [kPa]} \qquad (4.2.2.3)$$

Δp_m – maximum shock wave overpressure acc. to 4.2.2.1, [kPa];
t – time, [s];
τ_+ – endurance of the shock wave overpressure phase acc. to formula 4.2.2.2, [s];
n = 1 for $\Delta p_m < 100$ kPa,
= 2 for $\Delta p_m > 100$ kPa.

4.2.2.4 Pulse of the shock wave overpressure shall be determined from the formula:

– for the air explosion:

$$i = 0.343\frac{G^{2/3}}{R}, \text{ [kPa s], dla } 1 \le \frac{R}{\sqrt[3]{G}} \le 16 \qquad (4.2.2.4\text{-}1)$$

– for the on-water explosion:

$$i = 0.529\frac{G^{2/3}}{R}, \text{ [kPa s], dla } 1 \le \frac{R}{\sqrt[3]{G}} \le 16 \qquad (4.2.2.4\text{-}2)$$

G – mass of TNT concentrated charge (TNT equivalent), [kg];
R – distance from the center of charge, [m].

4.2.3 Impact Load on Hull Side Shell

4.2.3.1 Maximum impact pressure acting on the division (side of the ship, deck, etc.), originated from acting perpendicularly shock wave, shall be determined from the formula:

$$q_m = 2\Delta p_m + \frac{6\Delta p_m^2}{\Delta p_m^2 + 7p_0}, \text{ [kPa]} \qquad (4.2.3.1)$$

Δp_m – maximum shock wave overpressure acc. to 4.2.2.1, [kPa];
p_0 – static air pressure by the division, [kPa].

Maximum impact pressure acting on the division, originated from the shock wave acting on the division under angle $0 < \alpha < 90°$, may be estimated from the diagram on Fig. 4.2.3.1.

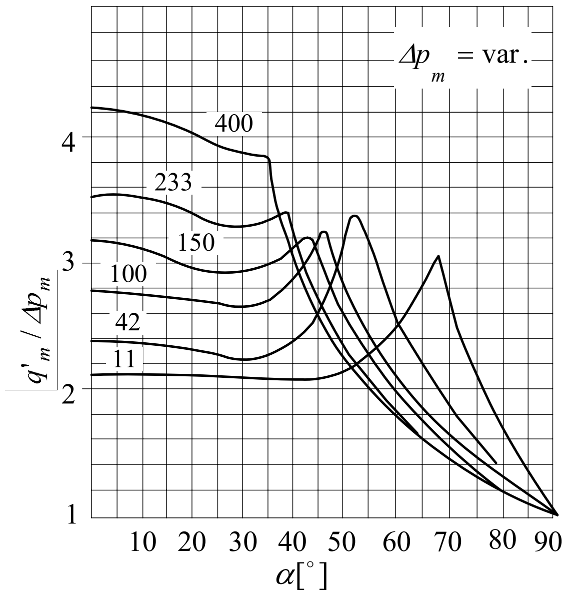


Fig. 4.2.3.1 Dependence $q'_m / \Delta p = f(\alpha)$ for various values Δp_m.

q'_m – maximum impact pressure on the division, originated from the shock wave acting at angle α, [kPa];

Angle α of the shock wave action, e.g. acute angle between the direction of the shock wave front movement and perpendicular to the surface of the division in the considered point.

4.2.4 Equivalent Static Air Explosion Load on the Structure

4.2.4.1 Strength of the structure may be checked for the design loads (pressures) acting statically, equivalent to impact loads.

4.2.4.2 Design loads for the vertical, and adjacent horizontal, uncovered fragments (elements) of the ship structure, shall be determined from the formula:

$$p_{obl} = k_d \cdot q_m^{'} \text{, [kPa]} \tag{4.2.4.2}$$

k_d = 1.5 – ship sides in the region of superstructure;
k_d = 1.3 – ship sides outside the region of superstructure, open deck (main) adjacent to the superstructure at the length equal to the superstructure height or breadth (the greater value shall be assumed), other important fragments of the structure;
k_d = 1.2 – vertical structures sheltering command stands and other important combat stands;
k_d = 1.0 – superstructures walls and other vertical fragments of the structure.
$q_m^{'}$ – maximum impact pressure on the division, originated from the shock wave acting at angle α, determined from the diagram on Fig. 4.2.3.1.

4.2.4.3 Design load for the horizontal uncovered fragments (elements) of the structure not listed in 4.2.4.2, shall be determined from the formula:

$$p_{obl} = k_d \cdot \Delta p_m \text{, [kPa]} \tag{4.2.4.3}$$

k_d = 1.3 – non-sheltered, and not adjacent to the superstructures, fragments of the open (main) deck, and other important horizontal fragments of the structure;
k_d = 1.2 – horizontal structures sheltering command stands and other important combat stands;
k_d = 1.0 – superstructures' decks and other horizontal fragments of the structure;
Δp_m – maximum direct shock wave overpressure determined acc. to 4.2.2.1, [kPa].

4.2.5 Scantling of the Structure on the Basis of Equivalent Static Loads

4.2.5.1 Thickness of the side plating, exposed to load from the air explosion shall not be less than the thickness determined from the formula:

$$t = 12.9 s \sqrt{\frac{p_{obl} \cdot}{afR_e}} \text{, [mm]} \tag{4.2.5.1}$$

l – length of the longer side of the plate area, [m];
s – length of the shorter side of the plate area, [m];
p_{obl} – design pressure , [kPa], acc. to 4.2.4;
$a = 1 + \left(\frac{s}{l}\right)^2$;
f – coefficient of material strengthening under momentary loads;
f = 1.2 – for steel; f = 1.09 – for alluminium alloys.

4.2.5.2 Plastic strength modulus for bending the stiffener with the side plating effective flange shall not be less than modulus determined from the formula:

$$W_{pl} = \frac{1000 p_{obl} l^2 b}{m\, f R_e}, \ [\text{cm}^3] \qquad (4.2.5.2)$$

W_{pl} – plastic strength modulus for bending the stiffener with the side plating effective flange. The effective flange shall be determined in accordance with principles of boundary capacity compressed plates theory.

l – span of the stiffener, [m], acc. to A/3.2.1;

b – width of the plating strake supported by the stiffener under consideretion, [m];

p_{obl} – design pressure acc. to 4.2.4, [kPa];

m = 12 – for the fixed-ends beam;

m = 8 – for free-ends beam;

f – coefficient of material strengthening under momentary loads;

f = 1.2 – for steel; f = 1.09 – for alluminium alloys.

4.2.5.3 Girders of the superstructures and above-water part of the hull strength shall be assessed in accordance with the requirements of Chapter B/14. Permissible stresses increased by 30% of the values determined acc. to B/14.5.3 shall be assumed. Summing zone and general bending stresses on the still water in accordance with the principles of B/14.5.3.2, additionally stresses from general bending, in a horizontal and vertical plane, originated from the air explosion shock wave impact (p. 4.2.5.4), shall be considered.

Value of still water bending moment shall be determined acc. to B/15.4, and as the value of the wave bending moment, 59% value determined acc. to B/15.5 shall be assumed.

4.2.5.4 Stresses from general bending in horizontal and vertical plane, originated from the air explosion shock wave impact, shall be determined. Application in calculations the ship structure model in a form of a beam is permissible.

4.2.5.5 For the ship structure mass optimization, FEM calculations in accordance with the principles defined in 4.2.6, are recommended.

4.2.6 FEM Calculations

4.2.6.1 For FEM calculations acc. to 4.2.6.2 i 4.2.6.3, elastic-plastic model of the structure material shall be assumed.

Dynamic analysis, assuming loads in a form of momentary impact pressure, shall be applied. For the front vertical walls uncovered fragments (elements) of the ships structure, assumption of the fading, in a time function, the shape of impact pressure course (see Fig. 5.5.3.2a), is recommended. Method of determination of t_1 shall be agreed PRS. Value of p_m shall be assumed as equal to value q'_m (p. 4.2.3.1). Other than fading, shape of impact pressure course may be accepted by

PRS subsequent to presentation of experimental research results, or relevant specialized literature. For the walls other than vertical front walls methodology of determination of the fading, in a time function, the shape of impact pressure course shall be agreed with PRS.

In elastic-plastic model of structure's material work, consideration of the material strengthening in result of momentary activity of pressure, is recommended. It manifests itself in increasing of yield point and decreasing of elongation, at which material specimen cracks during tensile test.

The above dependence shall be determined on the basis of experimental research or specialized literature, and presented to PRS for acceptance.

Deformations, originated in effect of shock wave impact, shall not impair integrity and gas-tightness of the superstructure and hull. While complying with this condition, plastic deformation of the side shell between stiffeners, if calculations performed show stiffeners' resistance to buckling under the compressive stresses from the general bending of the hull, are permissible.

4.2.6.2 Assuming momentary impact pressure action, the analysis shall be performed for:

.1 shifts and stresses in a single shell plate with consideration of membrane forces. It is recommended to adopt the model in a form of the shell strip with a unitary width, taking into account the axial forces and fixing the ends of the strip. Calculations shall be carried out in the range of large displacements, taking into account plastic deformations. It is permissible to extend the average area of the central plate between stiffeners amounting to no more than 10% of relative elongation A_5 of material used.

.2 shifts and stresses for the single stiffener with the effective flange. Fixing of the stiffener ends, and disregard to deflection of plating between stiffeners, shall be assumed. Stresses shall not exceed yield point R_{edyn}, where R_{edyn} – yield point of the material in the impact load conditions.

4.2.6.3 Assuming momentary loads of impact pressure, analysis of shifts and stresses in spherical segment containing walls and the uppermost continuous deck of the superstructure within one bulkhead division, shall be made. Methodology of the calculations and values of permissible stresses shall be assumed in accordance with requirements of 4.2.5.3.

4.2.6.4 Stresses from the general bending in the vertical and horizontal plane, assuming momentary impact pressure, shall be determined. Application in calculations of the ship structure model in a form of a beam is permissible. For the ships with length of $L_0 \geq 70$ m, analysis of deflections and stresses in their structure, assuming momentary impact pressure on the above-water part of the ship, applying ship structure model as a three-D FEM model, is recommended.

4.2.6.5 FEM calculations methodology shall be agreed with PRS.

4.2.6.6 Calculations made, and their results, shall be submitted for PRS consideration.

4.3 Underwater Explosion

4.3.1 General

4.3.1.1 Scheme of Underwater Explosion Conduct

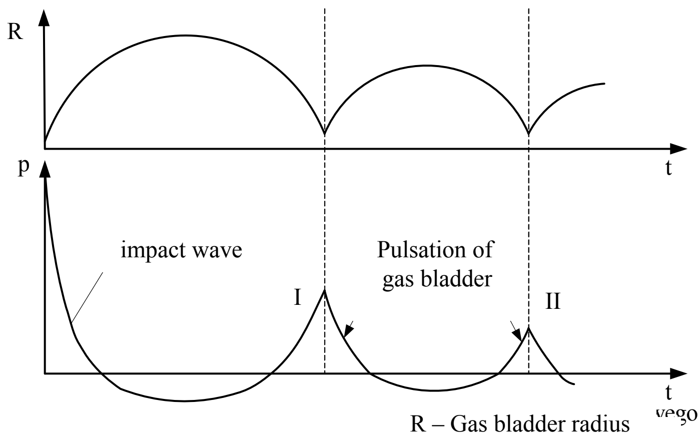


Fig. 4.3.1.1 Pulsation of the gas bladder

When analysing effect of the underwater explosion to the ship's hull, the following phenomenon shall be taken into account:

1) pulsation of the gas cavity. When forming, gas bladder expands until the maximum radius, at which the gas pressure reaches a minimum value substantially below the hydrostatic pressure. Gas bladder begins to sharply decrease when its volume. As a consequence, the pressure p inside the bladder increases, causing that, after a short time, the gas bladder begins to expand again. This phenomenon is repeated several times, before the gas bladder does float to the surface of the water (Figure 4.3.1.1).

   Effect of the gas bladder pulsation is a general vibration of the hull ("whipping") – see p. 4.3.8. This phenomenon is compounded when the ship's hull vibration free frequency is close to the frequency of pulsation of gas bladder.
2) the impact of local water shock wave through the expansion of the gas bladder formed from explosive charge detonation. The impact of local water shock wave, while omitting the impact of the gas bladder, results in pressure pulse propagation and formation of the hull's beam bending vibrations.

   Shock wave, hitting the division, is reflected and refracted (Figure 4.3.4.1). This phenomenon is further complicated by the fact, that the movement of the plating, under the shock wave influence, causes a sharp drop in the pressure wave, which leads to the phenomenon of cavitation.

   Considerable velocity of the shell plate bending requires taking into account the phenomenon in determining the pressure acting on the plate.

The complex nature of the underwater explosion process causes, that the analytical or numerical methods for assessing the strength of the structure are not sufficiently certain. Great importance in enhancing the impact resistance of the structures is the appropriate shape of the structure nodes, minimizing stress concentration.

Certainty of results, as to the structural behaviour under the action of underwater shock wave, can be achieved only with a test model of the hull structure's fragments in 1:1 scale. Therefore, in the case of minehunters or combat ships, which are required specified resistance against the underwater explosion, it is advisable to perform tests to verify the model calculations.

In sub-chapter 4.3.3, formulae for approximate estimation of loads parameters in the calculation of the ship's structure response for impact loads of underwater ex-plosions are given.

In the case of mine-hunters and combat ships, for which the Purchaser has required a specific resistance to underwater explosion, FEM calculations of the ship's hull response, according to principles set out in section 4.3.4 – if model tests referred to above have not been carried out, shall be performed.

4.3.1.2 If the gas bladder, in effect of the underwater explosion, is of such size, that the distance of its centre from the ship's hull is less than two maximum bladder's radiuses, then major local destruction of the hull in result of the explosion shall be expected.

In this case conducting local strength analysis becomes inappropriate.

4.3.2 Impact Number

4.3.2.1 The ship's structure shall be adequately resistant to underwater explosions. Conventional measure of the ship's impact resistance is the impact number, determined from the formula:

$$u = \frac{\sqrt{G}}{R} \qquad (4.3.2.1)$$

G – mass of the concentrated TNT charge (TNT equivalent), [kg];

R – the distance from the ship's side shell to the centre of the charge (see Fig. 4.3.2.1):

$R=\sqrt{F^2+(K-T)^2}$, [m];

F – the distance from the ship's side shell to the explosion epicentre [m];

K – immersion depth of the charge, [m];

T – ship's draught, [m].

Values of G and R are determined by the Purchaser in TTD (tactical-technical data).

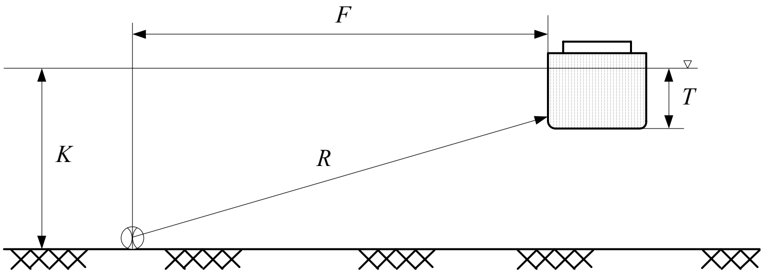


Fig. 4.3.2.1 The distances for impact number estimation

4.3.2.2 Recommended values of minimum impact number, for selected classes and sub-classes of the ships, assuming, that the explosion of the charge takes place on the sea bed, at 30 m depth, in a plane of midship section, under the hull in a plane of symmetry, are presented in Table 4.3.2.2.

Table 4.3.2.2
Recommended Values of Minimum Impact Number

Type of the ship	Full displacement D [t]	Minimum impact number u
Corvette	1000	0.32
Frigate	2500	0.34
Roadstead Minesweeper	200	0.35
Base Minesweeper	500	0.35
Sea Minesweeper	1000	0.40
Mine hunter	600	0.36
Small landing ship	500	0.20
Medium landing ship	1500	0.25
Large landing ship	2500	0.30
High-speed combat ship	250	0.25
	500	0.30
High-speed cutter	100	0.20
Transport ship	-	0.20
Tanker	-	0.20
Rescue ship	-	0.20

4.3.2.3 For underwater anti-mine vehicles and floating trawls it is required, that the impact number is contained in the range of 0.35 to 0.40.

4.3.2.4 If the impact number is greater than 0.34, or the ship's $L_0 \geq 50$ m, and the impact number is greater than 0.31, the hull general strength calculations, in accordance with requirements of sub-chapter 4.3.7, shall be performed.

4.3.3 Approximate Estimation of Underwater Shock Wave Parameters

4.3.3.1 Parameters of the underwater shock wave are calculated for the spherical charges of TNT. Concentrated charges, such as mines, depth charges or torpedoes are assumed as spherical, and their radius shall be determined from the formula:

$$r_o = 0.052\sqrt[3]{G}\text{ , m} \qquad (4.3.3.1)$$

G – mass of the concentrated TNT charge (TNT equivalent), [kg].

4.3.3.2 TNT equivalent of the charge shall be determined from the formula:

$$G = G_1 \frac{Q_1}{Q}\text{ , [kg]} \qquad (4.3.3.2)$$

G_1 – mass of the explosive charge, [kg];
Q_1 – specific energy of the explosive charge, [kJ/kg];
Q – specific energy of TNT explosion, $Q = 4187$ kJ/kg.

4.3.3.3 Parameters of the underwater shock wave

Maximum pressure of the underwater shock wave for the compressed TNT charges shall be determined from the formula:

$$p_m = A\left(\frac{r_o}{R}\right)^n\text{ , [MPa]} \qquad (4.3.3.3)$$

A, n – coefficients with values:

$A = 13.97$; $n = 1.95$ for $r_0 < R \le 5r_0$
$A = 52.3$; $n = 1.13$ for $5r_0 < R \le 1000r_0$
$A = 128$; $n = 1$ for $1000r_0 < R$;

r_0 – radius of the spherical explosive charge acc. to 4.3.3.1, [m];
R – the distance from the centre of the charge, [m].

4.3.3.4 Course of the shock wave pressure in time function presents following relation:

$$p(t) = p_m e^{-\frac{t}{\Theta}}\text{ , [MPa]} \qquad (4.3.3.4\text{-}1)$$

p_m – maximum pressure (wg 4.3.3.3), [MPa];
t – time, [s];
Θ – shock wave time-constant
– determination of the approximate value of the time-constant from the following formula is recommended:

$$\Theta = 0.1\sqrt[4]{GR}\cdot 10^{-3}\text{ , [s]} \qquad (4.3.3.4\text{-}2)$$

G – mass of the concentrated TNT charge (TNT equivalent), [kg];
R – the distance from the charge centre, [m].

4.3.3.5 Pressure pulse of the shock wave shall be determined from the formula:

$$i = 5.768 \frac{G^{0.63}}{R^{0.89}} 10^{-3}, \text{ [MPas]} \qquad (4.3.3.5\text{-}1)$$

G – mass of the concentrated TNT charge (TNT equivalent), [kg];
R – the distance from the charge centre, [m].

In rough calculations application of the following formula is permitted:

$$i = p_m \Theta, \text{ [MPas]} \qquad (4.3.3.5\text{-}2)$$

p_m – maximum pressure (acc. 4.3.3.3), [MPa];
Θ – time-constant of the shock wave (acc. formula 4.3.3.4-2), [s].

4.3.4 Parameters of the Underwater Shock Wave on the Media Border

4.3.4.1 In simplified engineer's strength calculations assumption is made, that the underwater shock wave hits perpendicularly motionless division (the hull side shell).

On the border of two media, underwater shock wave, incident at angle α, reflexes at the angle α', and refracts at angle α'' (Fig. 4.3.4.1). In this respect, the following is distinguished:
- incident wave,
- reflected wave,
- refracted wave (penetrating).

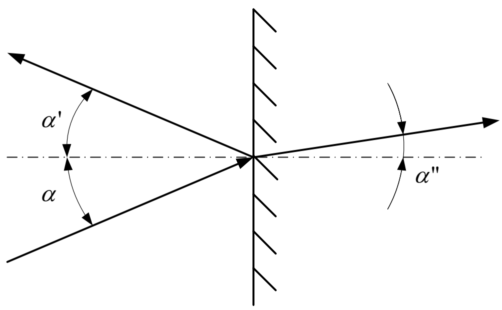


Fig. 4.3.4.1 Reflection and refraction of the underwater shock wave on the media border

4.3.4.2 Course of pressure in a shock wave reflected from the motionless obstacle is defined in the equation:

$$p_{11}(t) = k_{11}(\alpha) \cdot p(t), \text{ [MPa]} \qquad (4.3.4.2)$$

$k_{11}(\alpha)$ – coefficient of the shock wave reflection from the division, depending on the incident angle, determined acc. to 4.3.4.3;
$p(t)$ – course of pressure in the incident shock wave, determined in 4.3.3.4, [MPa].

4.3.4.3 Coefficient of the shock wave reflection from the motionless division, at the incident angle $\alpha = 0$, shall be determined from the formula:

$$k_{11} = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad (4.3.4.3)$$

Z_1 – acoustic resistance of the medium 1 (water), [kg/m^{2}s] (see 4.3.4.4);

Z_2 – acoustic resistance of the medium 2 (division), [kg/m^{2}s]

For $\alpha \neq 0$ procedure of determination of k_{11} value shall be agreed with PRS.

4.3.4.4 Acoustic resistance of medium shall be determined from the formula:

$$Z = \rho \cdot C \text{, [kg/m}^2\text{s]} \quad (4.3.4.4)$$

ρ – medium density, [kg/m^3];

C – medium acoustic velocity, [m/s].

Coefficient of the shock wave reflection (at incident angle $\alpha = 0$), as well as density of selected materials are presented in Table 4.3.4.4.

Table 4.3.4.4
Reflection Coefficient k_{11}

Material of medium	Density [kg/m^3]	Reflection coefficient k_{11}
Steel	7800	0.93
Aluminium alloys	2800	0.81

4.3.4.5 Influence of the sea bottom on the parameters of shock wave, acting on the hull side shell, shall be considered where the concentrated charge explodes over the sea bottom at the distance H_d complying with condition:

$$0 \leq H_d \leq 9\sqrt[3]{G} \text{, [m]} \quad (4.3.4.5\text{-}1)$$

G – mass of the concentrated TNT charge (TNT equivalent), [kg].

Influence of the sea bottom is considered by multiplying the numeral values of the following by the coefficient k_1 (determined acc. to formula 4.3.4.5-2):

.1 maximum pressure of the underwater shock wave p_m, determined from formula (4.3.3.3);

.2 underwater shock wave pressure pulse i, determined from 4.3.3.5.

Numeral value of the coefficient k_1 shall be determined from the formula:

$$k_1 = 1.4 - \frac{0.4}{9\sqrt[3]{G}} H_d \quad (4.3.4.5\text{-}2)$$

H_d – distance of the charge centre from the sea bed, [m];

G – mass of the concentrated TNT charge (TNT equivalent), [kg].

4.3.5 Impact Load on the Hull Side Shell

4.3.5.1 Phenomena of the impact load on the hull side shell occur on the borders of three media:
- medium 1 – water;
- medium 2 – material of division/side shell;
- medium 3 – the hull interior (air).

Determined from the formulae (4.3.5.2) i (4.3.5.3) velocities provide for estimation of the extreme deflections and stresses in the shell. Method of calculating the motion parameters does not include the cavitation phenomenon, happening in the water – shell boundary layer.

4.3.5.2 The side shell velocity under effect of impact load is described by the following dependence:

$$v(t) = \frac{(1+k_{11})i\ 10^6}{\rho_s(\beta-1)}\left(e^{-\frac{t}{\Theta}} - e^{-\frac{\beta t}{\Theta}}\right), \text{[m/s]} \qquad (4.3.5.2)$$

t – time, [s];
k_{11} – coefficient of the reflection on the water – shell border, acc. to 4.3.4.3;
i – the shock wave pressure pulse, acc. 4.3.3.5, [MPa s];
Θ – the shock wave time-constant, acc. to formula (4.3.3.4-2), [s];
ρ_s – surface density of the division mass:

$\rho_s = \rho d$, [kg/m^2]

ρ – division's material density, [kg/m^3];
d – division thickness, [m];

$\beta = \beta_1 + \beta_3$,

$\beta_1 = Z_1 \dfrac{\Theta}{\rho_s}$;

Z_1 – acoustic resistance of the medium 1 (water), acc. to formula (4.3.4.4), [kg/m^{2}s];

$\beta_3 = Z_3 \dfrac{\Theta}{\rho_s}$;

Z_3 – acoustic resistance of the medium 3 (air), acc. to fromula (4.3.4.4), [kg/m^{2}s];

4.3.5.3 Maximum velocity of the division shall be determined from the formula:

$$v_m = \frac{(1+k_{11})i\ 10^6}{\rho_s(\beta-1)}\left(e^{\frac{1}{1-\beta}} - e^{\frac{\beta}{1-\beta}}\right) \le \frac{i\ 10^6}{\rho_s}, \text{[m/s]} \qquad (4.3.5.3)$$

$k_{11}, i, \beta, \rho_s, e$ – as in 4.3.5.2.

4.3.5.4 The time of occurrence of the maximum velocity of the division shall be determined from the formula:

$$t_m = \frac{\Theta \cdot \ln \beta}{\beta - 1}, \text{ [s]} \tag{4.3.5.4}$$

Θ, β – as in 4.3.5.2.

4.3.5.5 The maximum velocity of the impact loaded side shell shall be determined from the formula:

$$a_m = \frac{1 + k_{11}}{\rho_s} p_m 10^6, \text{ [m/s}^2\text{]} \tag{4.3.5.5}$$

k_{11}, ρ_s – as in 4.3.5.2;

p_m – the maximum pressure (acc. 4.3.3.3), [MPa].

4.3.5.6 The mean acceleration of the impact loaded side shell shall be determined from the formula:

$$a_{sr} = \frac{v_m}{t_m}, \text{ [m/s}^2\text{]} \tag{4.3.5.6}$$

v_m – the maximum velocity of the division, acc. to formula (4.3.5.3), [m/s²];

t_m – time of occurrence of the maximum velocity of the division, acc. to formula (4.3.5.4), [s].

4.3.6 FEM Calculations

4.3.6.1 In the calculations mentioned in 4.3.6.3 and 4.3.6.4 elasticplastic model of the structure material shall be applied. Dynamic analysis shall be applied, assuming the load in the form of short-term operating pressure. Calculation methodology specified in p. 4.3.6.3 takes into account the phenomenon of cavitation accompanying the rapid movement of the plating.

4.3.6.2 When assessing the response of the structure, it can be considered permissible, that the medium elongation of the surface of the middle plate between the stiffeners amounts to no more than 10% relative elongation A5 of the material applied, measured in the tensile test.

Stresses in stiffeners shall comply with the condition:

$$\sigma \le R_{e\,dyn} \tag{4.3.6.2}$$

R_{edyn} – yield point of the material under the impact, [MPa];

It is recommended, that yield point of the material under the impact is determined experimentally, or on the basis on specialized literature, and submitted to PRS for acceptance.

Allowable normal stresses in girders, including stresses from the zone bending and the general bending of the hull on the calm water and the waves, are equal to the yield strength of material R_e.

The value of the bending moment in still water shall be determined acc. to B/15.4. As the value of the wave bending moment, 59 % of the value determined acc. to B/15.5 shall be assumed.

Allowable value of reduced stresses, determined with disregard to normal stresses from the hull general bending stresses, is equal to yield strength of the material, R_e.

4.3.6.3 Analysis of the structure response to the impact load shall be performed in the following scope:

.1 Determination of the shifts and stresses for the hull structure in the area of one bulkhead spacing under the pressure described by the formula (4.3.6.3-1).

$$p(x,y,z)=(1+k_{11})p_m e^{\frac{-t}{\Theta}} - \rho C_0 \frac{\partial w(x,y,t)}{\partial t} \cdot 10^{-6} \text{ , [MPa]} \qquad (4.3.6.3\text{-}1)$$

k_{11} – acc. to 4.3.4.3;

p_m – acc. to 4.3.3.3;

Θ – acc. to 4.3.3.4;

t – time, [s];

ρ = 1000, [kg/m^3], water density;

C_0 = 1450[m/s], acoustic velocity in water;

w – deflection of the side shell, measured in the direction of movement of the shock wave from underwater explosion, [m];

(x, y) – side shell plane.

During calculations $p(x, y, z) = 0$ shall be assumed in points, where stresses determined from the formula (4.3.6.3.2-1) take the negative values.

Non-shift support of the plating, stiffeners and girders on the transverse bulkheads, sides and decks shall be assumed.

For determination of the structure deformations application of equation of motion in a following form is recommended:

$$M\ddot{X} + D\dot{X} + KX = Q \qquad (4.3.6.3\text{-}2)$$

M – innertia matrix;

D – damping matrix, arising as a result of the existence of constituent containing $\frac{\partial w(x,y,t)}{\partial t}$ in equation (4.3.6.3-1);

K – rigidity matrix;

Q – single-column matrix of generalized forces components of a term: $\left(1+k_{11}\right)p_m e^{\frac{-t}{\Theta}}$ of equation (4.3.6.3-1);

$\ddot{X}$ – single column matrix of generalized accelerations;

$\dot{X}$ – single column matrix of generalized velocities;

X – single column matrix of generalized co-ordinates.

.2 Determination of shifts and stresses of the bulkhead with the initial curvature of the bending neutral layer.

Calculations and their results shall be submitted to PRS for consideration.

4.3.7 General Strength and Hull Vibrations

4.3.7.1 Calculations of the hull general strength and transverse vibrations analysis, with consideration of the impact load, shall be performed for the ships listed in 4.3.2.4. Impact bending moment shall be determined by the FEM method, applying the hull model in a form of the beam, or 3-D FEM model, and the pressure defined by the formula (4.3.3.4-1). In the case of 3-D model, it is recommended, that influence of the deflection of side shell and stiffeners to the pressure acting on the hull – see formula (4.3.6.3-1) is taken into account.

Calculations and their results shall be submitted to PRS for consideration.

4.3.7.2 For the assessment of the ability of the hull to transfer the shock loads caused by the non-contact underwater impact, it is recommended that the border strength criterion defined in 4.3.7.3 is assumed.

4.3.7.3 The general hull strength shall fulfill the following criteria:

.1 For the hulls with the superstructures of aluminum alloys, included in the hull general strength:

$$\frac{M_{gr}}{M_{obl}} \geq 1.35 \qquad (4.3.7.3\text{-}1)$$

.2 For the steel hulls, which superstructures are not included in the hull general strength:

$$\frac{M_{gr}}{M_{obl}} \geq 1.15 \qquad (4.3.7.3\text{-}2)$$

M_{gr} – boundary bending moment for the hull, calculated in accordance with Annex Z1;

M_{obl} – design bending moment:

$$M_{obl} = M_s + 0.8M_w + M_{ud} \qquad (4.3.7.3\text{-}3)$$

M_s – still water bending moment, acc. to B/15.4, [kNm];

M_w – wave bending moment, acc. to B/15.5, [kNm];

M_{ud} – impact bending moment caused by the non-contact underwater explosion acc. to 4.3.7.1, [kNm].

4.3.7.4 Calculations of the boundary bending moment shall be made for:
- at least one hull section in the region of midship, if the design bending moment reaches its maximum value on the midship;
- at least two sections, if the design bending moment reaches its maximum value outside the midship region – in this case, besides of calculation of midship bending moment, its calculation in the region of design bending moment maximum value shall be performed.

4.3.7.5 Calculations and their results shall be submitted to PRS for consideration.

4.3.8 General Vibrations in Effect of Gas Bladder Pulsation („whipping")

4.3.8.1 Vibration appearing in the ship's hull due to impacts on the plating, caused by the pulsating pressure of the gas bladder formed during an underwater explosion, can cause severe structural damage to the ship. It is recommended to analyse the strength of the hull under whipping conditions for ships with assumed shock number > 0.34 (see 4.3.2.1).

4.3.8.2 Simplifieed vibration analysis may be performed by comparing the hull beam free vibrations period to the duration of the first pulse of the gas bladder T (see Fig. 4.3.1.1):

$$T = 2.108 \frac{G^{1/3}}{(K+10)^{5/6}}, \text{ [s]} \qquad (4.3.8.2)$$

G – mass of the concentrated TNT charge (TNT equivalent), [kg],
K – depth of the charge immersion during explosion, [m].

4.3.8.3 For advanced analysis of the general hull vibrations caused by the underwater explosion, specialized, approved by PRS, computer programmes shall be utilized.

4.3.8.4 The ship hull vibration analysis shall take into account the impact of shear on the deformation of the hull. Water flow can be modelled using the strip method (strip theory). The model of an ideal fluid, i.e. inviscid and in-compressible, may be applied.

Behaviour of the gas bladder may be analysed using the ideal gas model.

The advanced version of the liquid flow calculations can be analysed by using the boundary element method (BEM).

4.3.8.5 Calculations and their results shall be submitted to PRS for consideration.

4.4 Explosion Inside the Ship

4.4.1 The essential role for the limitation of the zone of damage in a result of explo-sion inside the ship has the strength of the bulkheads dividing the ship into compartments. The length of the compartments shall be determined taking into account the size of an explosive charge, exploding inside the hull, given in the technical and tactical assumptions.

4.4.2 Thickness of the bulkheads plating shall not be less than 4 mm.

In the case of bulkheads made of higher tensile steel, application of steel grade D or E is recommended.

Where it is practically possible and justified, it is recommended to apply double bulkheads, in combination with double sides, withstanding static pressure of 600 kPa.

4.4.3 Due to the fact, that during the explosion, welded joints of the bulkhead and the adjacent structure break as the first, therefore the increase of the impact resistance of welded joints by application of full penetration welding and/or use of austenitic electrodes for fillet welding shall be aimed at.

Passages of pipelines led through the bulkheads shall be fitted with compensation elements located on both sides of the bulkhead.

Pipelines passages should be located near the edge of the bulkhead in place, where the relative movement of the bulkhead plating are the smallest.

4.4.4 Number of equipment elements fitted on the bulkhead shall be limited to a minimum.

4.4.5 Pipelines and accepted by PRS ducts, casings and other bulkhead passages shall be provided with flaps, valves, and other devices preventing penetration of the shock wave to neighbouring and further compartments.

4.5 Protection Against Splinters and Shells of Small Arms

4.5.1 Purchaser in each case designates compartments and location, as well as kind of pipelines and cables requiring protection against splinters and small arms shells.

It is recommended that in the list of protected compartments, especially important for the ship surveillance compartments, equipment and regions, and at least: MCP, BCI, communication, command and ship control center, as well as ammunition chambers, magazines and parks were included.

4.5.2 The above mentioned facilities shall be located inside the ship so that they are protected by the outer skin of the hull and longitudinal bulkhead or appropriate ballistic shields inside the ship. It is recommended that the longitudinal bulkhead/shield is located, as far as possible, at least 1 m from the plating of the external shell.

Thickness of the longitudinal bulkhead plating and/or application of armour or other shielding/ballistic materials (e.g. kevlar) shall be established in accordance with tactical-technical requirements and principles of ballistic shields selection.

5 LOADS FROM ARMAMENT AND THE STRUCTURE RESPONSE

5.1 General

In the present Chapter requirements relating to the hull structure loads from armament during firing guns and taking off missiles are specified.

5.2 The Loads from the Guns Recoil

5.2.1 Recoil force shall be determined on the basis of technical documentation provided by the manufacturer.

5.2.2 Structure response to the loads acc. to 5.2.1 (deflections and stresses) shall be determined in accordance with 5.5, depending on relation between the time of recoil action and natural vibration period of the supporting structure.

In preliminary calculations maximum deformations and stresses in a hull structure may be determined as a static loads response amounting to 160% of maximum value of recoil force.

Where guns are placed directly above bulkheads or the hull divisions, load increase factor may be reduced from 160% to 120%.

5.2.3 Analysis of the structure response to loads from recoil shall be performed for many actual angles of barrel shot settings, against the ship's plane of symmetry (PS) and the base plane (BP).

The values of angles 0 °, ± 45 °, ± 90 °, ± 135 and 180 to the PS shall always be taken into account, as well as the minimum and maximum angle of the barrel axis against the base plane and angle equal to the arithmetic mean of these two values.

5.3 Loads from Shot Impact Wave

5.3.1 During the shooting a short blast is generated in a form of pressure imposed on the construction of the hull (deck) near the muzzle. Value of this pressure, as a function of distance from the muzzle and the angle between the line of the barrel axis and the radius connecting the barrel end with the point, where the pressure is defined (see Fig. 5.3.3) and the value of pressure as a function of time are usually given in the technical documentation of armaments, delivered by the manufacturer.

Strength calculations of the structure imposed to the above pressure consist in application of substitute static pressure, with values determined from 5.5.

5.3.2 In the case of quick-firing cannons (30 rounds per minute and more) there is a danger of generating excessive vibration of the hull structure. Such situations are in each case separately considered by PRS.

5.3.3 In the case where the pressure parameters described in 5.3.1 are unknown, substitute static pressure p_z may be determined from the formula:

$$p_z = 2(1+\cos\alpha)\left(\frac{K_d}{r}\right)^{3/2} \cdot 10^3, \text{ [kPa]} \tag{5.3.3}$$

where:

α – an angle between cannon barrel axis and point *P*, for which the pressure is calculated (Fig. 5.3.3);

K_d – cannon's calibre, [mm]; the above formula is valid for 80 mm ≤ K_d ≤ 120 mm;

r – distance of *P* point to the barrel end, [mm] (Fig. 5.3.3).

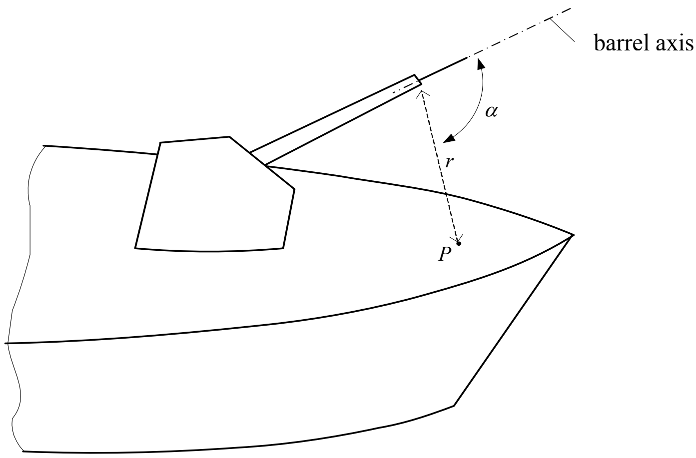


Fig. 5.3.3 Parameters for pressure p_z calculations

5.4 Loads from Rocket Engines

5.4.1 Static loads acting on the hull structure (e.g. deck) from the projectile's rocket engine exhaust stream may be determined from the formula:

$$p_z = f_d \frac{F}{A} \frac{\sin\alpha}{\sin\alpha + tg\beta \cdot \cos\alpha}, \text{ [kPa]} \tag{5.4.1}$$

where:

f_d – coefficient taking into account the variation of pressure versus time; f_d may be assumed 1.5;

F – engine thrust force, [kN];

α – angle between the engine axis and the structure surface (Fig. 5.4.1); valid for 25° < α < 90°;

β – angle of the exhaust stream deviation (rys. 5.4.1); β may be assumed 3°;

A – area of the surface loaded by the exhaust stream, [m^2] (Fig. 5.4.1).

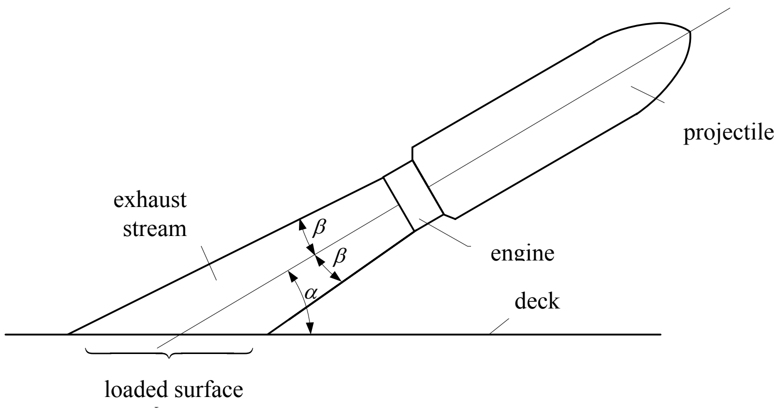


Fig. 5.4.1 Load from the exhaust stream

5.4.2 The deck in the area of exhaust stream impact shall be protected against high exhaust temperature and blow of the contained in it solid particles – e.g. by covering with adequate coating or lining, or by application of exhaust gases guides and protective grids.

5.5 FEM Calculations, Substitute Static Loads and Permissible Stresses

5.5.1 General

5.5.1.1 In the sub-chapter, 5.5 principles are given for calculations of the maximum deformations and stresses in the hull structure elements under momentary, variable in time, loads defined in 5.2, 5.3 and 5.4.

5.5.1.2 FEM calculations of the structure response to the loads mentioned in 5.5.1.1, in accordance with the principles defined in 5.5.2, are recommended.

Assessment of the structure response to the above loads may be performed acc. to 5.5.3.

5.5.2 FEM Calculations

5.5.2.1 FEM calculations are recommended in situations, where the hull structure elements under loads of 5.5.1.1 can not be sufficiently precisely modelled in a form of simple plate or stiffeners models, for which free vibrations frequencies may be calculated in accordance with the formulae given in 5.5.4.

5.5.2.2 Using the FEM model of the ship hull structure elements, equations of motion of a finite number of freedom are formulated. System of ordinary differential equations containing the coefficients of the time-dependant values (generalized forces dependant on the structure loads) is numerically integrated in time domain.

In result of such calculations approximate values of deflections and stresses in the structure, in a time function, are determined. The maximum values of stresses shall not exceed the permissible values given in 5.5.5.

5.5.3 Substitute Static Pressures

5.5.3.1 In the case where calculation model may be brought to simple plate (fragments of plating) or beam (plating stiffeners together with their effective flange), application of the concept of substitute static loads, resulting in the structure deflections and stresses values near to the parameters maximum, variable in a time function due to variable loads, is advisable.

Substitute static pressure P_{st} is determined from the formula:

$$P_{st} = f_d \cdot P_m \tag{5.5.3.1}$$

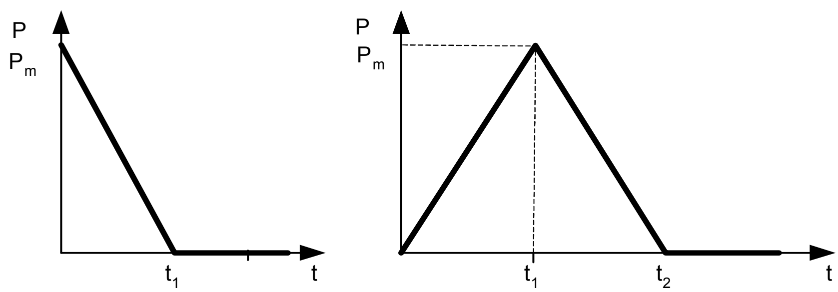
where:

f_d – numerical coefficient,

P_m – the maximum value of the, variable in a time function, pressure.

5.5.3.2 Values f_d for the pressures diagrams in a time function are presented on Fig. 5.5.3.2, and those, which may constitute approximation of the actual loads, are given in Table 5.5.3.2.

T is the period of plate or beam basic free vibrations, calculated acc. to 5.5.4.



a) fading pressure b) triangle pressure variation

Fig. 5.5.3.2 Simplified diagrams of the pressure in a time function

Table 5.5.3.2 Values of f_d

$\frac{t_1}{T}$	Triangle pressure variation	Fading pressure
1	2	3
0.1	0.31	0.30
0.2	0.61	0.60
0.3	0.88	0.85
0.4	1.10	1.05

1	2	3
0.5	**1.27**	**1.20**
0.6	**1.39**	**1.30**
0.7	**1.47**	**1.40**
0.8	**1.50**	**1.48**
0.9	**1.51**	**1.53**
1.0	**1.51**	**1.60**
1.2	**1.44**	**1.66**
1.4	**1.34**	**1.72**
1.6	**1.23**	**1.73**
1.8	**1.10**	**1.75**
2.0	**1.00**	**1.75**
2.2	**0.95**	**1.76**
2.4	**1.02**	**1.78**
2.6	**1.09**	**1.79**
2.8	**1.13**	**1.80**
3.0	**1.16**	**1.80**
3.2	**1.17**	**1.81**
3.4	**1.13**	**1.82**
3.6	**1.08**	**1.83**
3.8	**1.06**	**1.83**
4.0	**1.00**	**1.83**
4.2	**0.98**	**1.83**
4.4	**1.01**	**1.84**
4.6	**1.05**	**1.85**
4.8	**1.08**	**1.85**
5.0	**1.09**	**1.85**
5.5	**1.06**	**1.87**
6.0	**1.00**	**1.87**

Note: Values of f_d for other values of t_1/T shall be determined by the linear interpolation.

5.5.4 Basic Free Vibrations Periods

5.5.4.1 Basic free vibrations of the steel rectangular plate restrained over its whole perimeter, in contact with air, may be determined from the formula:

$$T = 0.18 \frac{sl}{t_p} \cdot \frac{1}{\sqrt{\left(\frac{l}{s}\right)^2 + \left(\frac{s}{l}\right)^2 + 0.605}}, \text{ [s]} \qquad (5.5.4.1)$$

where:

s – length of the shorter plate side, [m];
l – length of the longer plate side, [m];
t_p – thickness of the plate, [mm].

5.5.4.2 The free vibrations period of the stiffener with its effective flange shall be determined from the formula:

$$T = C \cdot l^2 \sqrt{\frac{m}{EI}\left(1 + \frac{EI}{1014 \cdot l^2 G\, A}\right)}, \text{ [s]} \qquad (5.5.4.2)$$

where:

s – length of the beam, [m];

m – beam mass per unit length, [kg/m];

i – moment of inertia of the transverse section, [cm^4];

a – shear section area (web area), [cm^2];

g – formal modulus (for steel *g* = *e*/2.6);

e – Young modulus, [mpa];

c – coefficient of values dependant on beam ends fixing:

c = 6.33 – for joined beam ends,

c = 2.81 – for fixed beam ends,

c = 4.08 – for one fixed, and other jointed ends.

5.5.5 Permissible Stresses

5.5.5.1 For calculations of the required plate thickness under the pressure acc. to 5.5.3.1, performed in accordance with the formula B/13.4.2.1-1, σ = 160*k*, MPa, shall be assumed.

FEM calculations acc. to 5.5.2 may be performed in a linear-elastic range, assuming permissible normal stresses value σ = 300*k*, MPa.

5.5.5.2 In stiffeners and girders calculations, following permissible stresses values shall be applied:

– normal stresses: σ = 180*k*, [MPa];
– mean tangent stresses in web: τ = 110k, [MPa];
– reduced stresses: $\sigma_{zr} = \sqrt{\sigma^2 + 3\tau^2}$ = 200*k*, [MPa].

6 DAMAGED HULL STRENGTH

6.1 General

6.1.1 Requirements of the present Chapter apply to general strength of the hull, in general bending condition.

The requirements are supplementary to the requirements of Chapter B/15, applicable to general strength of the intact hull.

6.1.2 Conventional damage of the hull, assumed acc. to 6.2 for calculations acc. to 6.3 may result from:
- projectile explosion inside the ship;
- underwater explosion;
- ship's bottom contact with the sea area bottom;
- collision with the floating object.

6.1.3 Applied in the damaged hull strength analysis ranges of damages, loads and criteria shall be recorded in *Loading Manual.*

6.1.4 The purchaser may decide, that the hull need not to comply with the criteria for damaged strength, determined in a sub-chapter 6.4.

6.2 Range of the Structure Damage

6.2.1 The Hull Damages from the Projectile Explosion Inside the Ship

In calculations, assumption shall be made, that due to projectile explosion total destruction of the hull structure elements in a selected transverse section (plating, stiffeners, girders) inside a circle of radius *R* (Fig. 6.2.1), took place.

The value of the radius *R*, which is to be taken for calculations, shall be determined by the Purchaser – on the basis of assumed projectile parameters. Location of the circle shall be assumed in accordance with the requirements of 6.3.3.2.

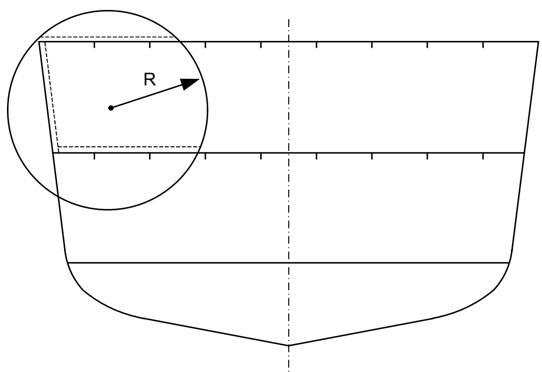


Fig. 6.2.1 The hull damaged region due to projectile explosion inside the ship

6.2.2 The Hull Damages from the Underwater Explosion

In calculations, assumption shall be made that, in effect of underwater explosion, total destruction of the ship's hull structure elements of the bottom or sides below the waterline (plating, stiffeners and girders in selected transverse section), at the length *l,* took place.

The value of *l* is determined by the Purchaser on the basis of assumed mass of the explosive load and co-ordinates of the explosion, in relation to the ship's co-ordinates.

6.2.3 The Hull Damages due to Collision with Floating Object

In calculations, assumption shall be made that, in effect of the collision total destruction of the ship's side structure elements in the following area took place:
- at the length of 5 m between neighbouring transverse bulkheads;
- at the depth of 1/5*B* (from the position of the side before damage, towards interior of the hull);
- from the waterline to the main deck level (the deck remains undamaged).

6.2.4 The Hull Damages due to the Ship's Contact with the Bottom

In calculations, assumption shall be made that, in effect of the contact with the bottom total destruction of the ship's structure elements in the following area took place:
- at the length of 5 m in any place from the midship towards the bow of the ship;
- at the width of 2.5 m;
- at the depth of 1 m from the bottom line before damage, and for the ships with double bottom not deeper than to the inner bottom (inner bottom remains undamaged).

6.3 Analysis Methods and Criteria

6.3.1 General

6.3.1.1 General strength of the damaged ship shall be checked for the design value of bending moment and design value of the transverse force determined acc. to 6.3.2.

6.3.1.2 The strength associated with the bending moments from general bending can be assessed using a simplified model assuming linear-elastic hull model – according to 6.3.3. The results of calculations according to 6.3.3, however, are conservative in their nature. Accordingly, it is advisable to check the limit strength of the damaged hull in the general bending conditions acc. to 6.3.4 (instead of the calculations according to 6.3.3).

6.3.1.3 The strength of the hull in shear conditions shall be assessed with application of linear – elastic hull model, acc. to 6.3.6.

6.3.2 Design Values of Bending Moments and Transverse Forces

6.3.2.1 Design values of bending moments M_{ob} shall be determined from the formula:

$$M_{ob} = M_{sf} + 0.8M_w, \text{ [kNm]} \tag{6.3.2.1}$$

where:

M_{sf} – value of still water bending moment in considered section, [kNm], determined with consideration of flooded watertight compartment, adequately to location of the damage to underwater part of the hull – acc. to 6.2. water level in the flooded compartment reaches the level of the waterline of the damaged ship. At determining m_{sf}, principles for m_s calculations, given in B/15.4, shall be applied;

M_w – wave bending moment, [kNm], determined acc. to B/15.15.1 for the section under consideration.

6.3.2.2 Design values of the transverse force, Q_{ob}, shall be determined from the formula:

$$Q_{ob} = Q_{sf} + 0.8Q_w, \text{ [kN]} \tag{6.3.2.2}$$

where:

Q_{sf} – still water shear force, [kN], for the considered section, determined with consideration of flooded watertight compartment, adequately to location of the damage to underwater part of the hull – acc. to 6.2. Water level in the flooded compartment reaches the level of the waterline of the damaged ship. At determining Q_{sf}, principles for Q_s calculations, acc. to B/15.9, shall be applied.

Q_w – wave transverse force, [kN], acting in the considered section, determined as Q_{wp} or Q_{wn}, acc. to B/15.10.

6.3.3 Strength Associated wit Bending Moments – Calculations in Linear – Elastic Range

6.3.3.1 The structure strength in regions of assumed damages located in areas of co-ordinates $x = -0.25L_0$, $x = 0$, $x = 0.25L_0$ (approximately) shall be considered. Depending on spatial division and the hull structure – checking the strength in more transverse sections may be required.

6.3.3.2 The hull section moduli, with reference to the horizontal neutral axis, in the places of assumed damages, shall be determined. The moduli values shall be determined in accordance with B/15.7.

The longitudinal hull members (plating, stiffeners and longitudinal girders) in damaged areas, defined in 6.2, shall be disregarded.

Location of damage areas mentioned in 6.2.1 and 6.2.2, in all realistic positions along the hull transverse section perimeter (bottom plating, side plating, upper deck, side walls of superstructures and deckhouses) so that at a given R or l value they cover the largest area of the structure, shall be considered.

6.3.3.3 The following criterion shall be complied with:

$$\frac{10^3 M_{ob}}{W} \le 0.95 R_e \qquad (6.3.3.3)$$

where:

M_{ob} – design moment – acc. to 6.3.2.1, [kNm];

W – the damaged hull transverse section modulus, with reference to the bottom or strength deck, [m^3], calculated for the structure net scantlings;

R_e – material yield point, [MPa].

Notes:

A) Criteria of the compressed plates stability in conditions of general bending with moment M_{ob} need not to be complied with.

B) The longitudinal stiffeners and girders shall comply with the stability criteria given in B/13.5.3 and B/13.5.4.

6.3.4 Strength Associated with Bending Moments – Calculations of Limit Moments

6.3.4.1 The structure strength shall be considered in sections determined in 6.3.3.1.

6.3.4.2 The hull limit moments, M_{gr}, [kNm], in sections determined in 6.3.4.1, shall be calculated.

Values of M_{gr} shall be calculated by the method presented in Annex Z1 – for the structure net scantlings.

The manner of accounting for the structure damaged elements, and the location of the damaged places shall be assumed acc. to 6.3.3.2.

Alternative calculations may be made acc. to 6.3.4.4.

6.3.4.3 The following criterion shall be fulfilled:

$$M_{ob} \le 0.9 M_{gr} \qquad (6.3.4.3)$$

where:

M_{ob} – the design bending moments determined acc. to 6.3.2.1;

M_{gr} – the limit moments determined acc. to 6.3.4.2 or 6.3.4.4.

6.3.4.4 Calculations of M_{gr} value may be performed with application of non-linear FEM model of the hull structure fragment comprising damaged region. Elastic-plastic deformations and geometrical non-linearity shall be taken into account. Such calculations are subject of PRS separate consideration.

6.3.5 Shear Strength

6.3.5.1 The strength of the damaged hull in shear conditions shall be checked in the transverse sections determined in 6.3.3.1, in which the side shell is damaged.

6.3.5.2 The following criterion shall be fulfilled:

$$\tau_{max} \leq 0.5R_e \qquad (6.3.5.2\text{-}1)$$

where:

τ_{max} – the maximum values of the tangent stresses in side plating, inner side plating or longitudinal bulkheads, corresponding to shear force Q_{ob} (see 6.3.2.2);

τ_{max} shall be determined in accordance with thin walled rods theory, taking into account the damage in considered section. in calculations assumption shall be made, that the neutral axis of the hull transverse section in the place of damage remains horizontal.

In the case of hulls with a single side and without longitudinal bulkheads, the condition determined by the formula 6.3.5.2-1 may be presented in the following, equivalent form:

$$10^2 \frac{|Q_{ob}| \cdot S_n}{I_n t} \leq 0.5R_e \qquad (6.3.5.2\text{-}2)$$

where:

Q_{ob} – design transverse force determined acc. to 6.3.2.2, [kn];

S_n, I_n – parameters determined acc. to B/15.11.1 i B/15.7, but for the transverse hull section with the damaged side plating;

t – thickness of undamaged side plating [mm], at the level, at which the other side is damaged.

6.3.5.3 The plating of the sides, inner sides and longitudinal bulkheads of the hull section in a place of damage, shall fulfil stability criteria in shear conditions for the tangent stresses determined in accordance with 6.3.5.2, given in *B*/13.4.3.

7 LANDING SHIPS HULL STRENTHENING

7.1 General

7.1.1 The requirements of the present Chapter are supplementary to the requirements of the Chapter B/6, concerning the bottom structure. They are applicable only to these parts of the ship's bottom, which may rest on the ground (sea bottom) in the region of the sea coast, during the ship motion towards the shore, and after its immobilization.

7.1.2 The requirements of the present Chapter rely on assumption, that the operation of settling the ship ashore (on the beach) is always conducted in accordance with the established procedures, assuring minimization of the impact loads in conditions of the ship's bottom contact with the ground. It is also assumed, that on the sea coast there are no rocks or stones forming the surface irregularities with heights greater than the height of reinforcing or cushioning belts, located at the bottom of the ship.

7.1.3 When determining scantlings of the landing ship's hull structure, impact load from the rolling breaker in the region of the sea shore, impact on the shore ground, as well as the ramps reaction forces induced by vehicles weight, shall be considered. The angle of inclination of the sandy seabed up to 2°, rake along the bottom of the ship in the bow section from 0° to 2°, and the speed of landing on the shore up to 3 knots shall be assumed.

In the case of the use of the bow and stern ramps for handling on the deep water military floating technique vehicles, the loads arising from the entire phase of these vehicles movement into the water, or their movement from the water to the ship, shall be taken into account.

7.2 Bottom Plating

7.2.1 The bottom plating thickness in regions exposed to reaction of the ground during and after settling the ship on the beach shall be determined acc. to Chapter B/6, and then increased by 20%. Applied thickness shall not be less than 7.0 mm.

7.3 Bottom Stiffeners and Girders

7.3.1 Spacing of the stiffeners in regions exposed to reaction of the ground during and after settling the ship on the beach shall not be greater than 500 mm. Section modulus of these stiffeners shall be greater by at least 20% from the values determined in accordance with the requirements of Chapter B/6.

7.3.2 In the bottom area, mentioned in 7.3.1, spacing of the full floors shall not be greater than: 1.5 m for transverse stiffening system, and 2.0 m for longitudinal stiffening system. From each side of the ship's plane of symmetry one more bottom side longitudinal, than required by Chapter B/6 requirements related to the structure elements arrangement, shall be fitted.

7.3.3 The ship's bottom girder scantling shall be determined acc. to requirements of Chapter B/6 and B/14. The loading condition characteristic for landing ships, where the bottom in the area defined in 7.3.1, is loaded by uniform pressure resulting from the ground reaction, shall be taken into account. Assumed to calculations area of that surface shall not be greater than 50% of the total area of the ship's bottom. Stresses in longitudinals due to general bending of hull resting on the ground, shall be regarded in calculations. The loads from the weight of vehicles in their realistic number and arrangement on the ship and on the ramps shall also be taken into account.

7.3.4 Bottom girders and stiffeners in the area mentioned in 7.3.1 shall be welded by continuous welding. Openings in girders' webs, in places of their connections with the side shell stiffeners, shall be blinded, or doubling plates shall be applied there.

7.4 General Strength

7.4.1 In the case of ships with length $L_o > 50$ m, calculations of the general strength required in Chapter B/15 shall be supplemented, taking into account load conditions for the ship resting with the bottom on the shore, under various realistic configurations of the ship support and loads from the ship interior, as well as ramps reaction. Bending moments and transverse wave forces may be disregarded in calculations (compare Chapter B/15), e.g. in formulae B/15.2.1 and B/15.11.1, $M_w = 0$ and $Q_w = 0$ may be assumed. The same, as in Chapter B/15, values of the permissible stresses σ and τ shall be assumed.

7.4.2 If, in the case of the ship with length of $L_0 > 50$ m, the possibility of the settling on the beach the ship's bottom in region $-0.2L_0 < x < 0.2L_0$ is expected, the required plating thickness and scantlings of the bottom girders in this area shall be separately considered by PRS.

7.5 Protective and Absorbing Longitudinals

7.5.1 For the small vessels, or the vessels constituting landing ships' equipment, it is recommended that protective or absorbing longitudinals, with a structure similar to the side fenders, are provided on their bottom. These longitudinals shall be fitted in the part of the bottom provided for resting on the ground, outside of the bottom plating, spaced about 1.5 m, in line of bottom longitudinals axis, and their height shall not be less than 100 mm.

7.5.2 Application of the strong protective steel longitudinals, made of rolled cylindrical shapes or of welded box structure is allowable.

7.5.3 Protective longitudinals or framing of the absorbing longitudinals shall be made of the same material as the bottom plating to which they are fitted and shall be protected against corrosion by means of protective layers.

7.5.4 Protective longitudinals or framing of the absorbing longitudinals shall be welded to the hull bottom plating by continuous welds. Their segments shall be face-welded before fitting to the hull. If such welding is impracticable, PRS may accept ceramic backing strip welding.

7.5.5 Ends of the protective longitudinals or absorbing longitudinals framing shall be bevelled to not less than 1:3, and shall extend over the floors or transverse stiffeners of the bottom plating for a distance of 30 do 50 mm. Welds in the region of the above elements shall be reinforced.

8 HELICOPTERS' LANDING GROUNDS AND VERTREP PLANES

8.1 General

8.1.1 Requirements of the present Chapter apply to ships with helicopters' landing grounds and/or VERTREP planes (a plane on a ship's deck, from which cargo can be loaded to the helicopter in hovering, or unloaded from such helicopter).

Design of the helicopters' landing grounds and VERTREP planes shall also comply with the requirements of *Defense Standard prNO-19A-206*.

8.1.2 In the present Chapter general structural requirements concerning helicopters' landing grounds and VERTREP planes, design loads and principles for calculation of the minimum required plating thickness, section modulus of the plating stiffeners, as well as checking of the girder system strength are given.

8.2 Descriptions and Explanations

In the present Chapter the following descriptions concerning loads are applied:

s t a t i c   l o a d – summary pressure Q_s of the helicopter's wheels on the landing ground deck, or pressure of cargo element on VERTREP plane, of value equivalent to the maximum helicopter's takeoff weight m, or the maximum weight of the cargo element ($Q_s = mg$; $g = 9.81$ m/s^2 – gravity);

d e s i g n   l o a d   f o r   t o u c h d o w n   a r e a – (determined acc. to *Defense Standard prNO-19A-206*) – load of value $3Q_s$;

d e s i g n   l o a d   f o r   c r i t i c a l   a r e a – (determined acc. to *Defense Standard prNO-19A-206*) – load of value $5Q_s$;

l o a d   i n   m a n e u v e r i n g   o r   p a r k i n g   c o n d i t i o n s – load corresponding to pressure p acting on the area of the wheel imprint or on the contact area of the cargo element with VERTREP plane, determined acc. to the formula (9.3.2.3-2) for $K_d = 1 + (0.5a_v / g)$, while the adopted to calculations K_d value shall not be less than 1.5.

8.3 Required Documentation

8.3.1 Documentation for Helicopters' Landing

Documentation submitted for approval shall contain following information:

.1 location and dimensions of the landing ground;

.2 dimensioned landing ground marking, designating regions for touchdown, maneuvering and parking (the requirements of the *Defense Standard prNO-19A-206* shall be taken into account);

.3 arrangement of devices fastening the helicopter's to the deck;

.4 helicopter's technical data assumed for design of the landing ground (the maximum weight, spacing of wheels or skids, the dimensions of the wheels or skids imprints);

.5 landing ground structural drawings;
.6 drawings determining designation and the equipment of compartments under the landing ground deck;
.7 designation of the emergency touchdown area (critical area);
.8 for the landing grounds, at which VERTREP plane is located – information referred to in 8.3.2, sub-paragraphs .1, .2, .3 and .4.

8.3.2 VERTREP Plane Documentation

Documentation submitted for approval shall contain following information:
.1 location of VERTREP plane;
.2 general dimensions and dimensions of area designated for lowering the cargo from the helicopter;
.3 an area provided for storage of the cargo and distribution of cargo fastening equipment;
.4 technical data of the cargo lowered from the helicopter, assumed for the design of the VERTREP plane structure (the maximum weight and dimensions);
.5 VERTREP plane structural drawings;
.6 drawings determining designation and the equipment of compartments under the VERTREP plane.

8.4 Helicopters' Landing Ground Plating, Stiffeners, Girders and Pillars

8.4.1 Plating

8.4.1.1 At determining required thickness of the landing ground plating, assumption shall be made, that the load from the helicopter's wheels may occur in any place of the area.

8.4.1.2 An assumption shall be made, that the load in touchdown conditions (see 8.2) is distributed uniformly over two wheels imprint areas (or wheels imprints envelope) of dimensions in accordance with the helicopter's technical documentation.

If the dimensions are not known, then the wheel imprint dimensions 0.2 m × 0.3 m (0.2 m – dimension in direction transverse to the wheel's axis) shall be adopted.

The identical to the above dimensions of the deck pressure area (e.g. 0.2 m × 0.3 m) shall be adopted in the case of the helicopter with skids..

8.4.1.3 Required thickness of the plating shall be determined from the formula (9.3.3.1), determining Q acc. to 9.3.4, where pressure p shall be assumed as a design load in landing conditions determined acc. to 8.2, distributed to wheels acc. to 8.4.1.2, and divided by the wheel imprint area (or wheels envelope).

8.4.1.4 Where under the landing ground compartments are provided, designated for continuous attendance by the personnel (crew accommodations, control stations, etc.), or for storage of liquid fuels, then the plating thickness shall be determined acc. to 8.4.1.3 adopting design load for the critical area (see 8.2).

8.4.1.5 Plating thickness of the touchdown area located on the strength deck in the middle part of the ship's hull shall be increased by 10% in relation to the thickness determined acc. to 8.4.1.3 or 8.4.1.4.

In the regions of the strength deck between centre part and outer parts, the required thickness *t* shall be determined by linear interpolation for *t* values determined as above and acc. to 8.4.1.3, compulsory for outer parts.

8.4.1.6 In the landing ground's areas designated for helicopters manoeuvering or parking, the required plating thickness shall be determined from the formula (9.3.3.1) for loads in manoeuvring conditions and loads in parking conditions (see 8.2).

In this case increase of plating thickness acc. to 8.4.1.5 is obligatory.

8.4.1.7 Plating in areas other than designated for landing, maneuvering and parking shall be determined as for decks, e.g. in accordance with Chapter B/8.

8.4.2 Stiffeners

8.4.2.1 At determining required section modulus for deck stiffeners in areas designated for landing, the requirements specified in 8.4.1.1 and 8.4.1.2, relating to loads from the helicopter's wheels, shall be applied.

8.4.2.2 The required section modulus shall be determined acc. to 9.4.2.

When assigning *Q* acc. to (9.4.3), pressure *p* shall be assumed as a load value determined acc. to 8.2, distributed to the wheels acc. to 8.4.1.2, and divided by the area of the wheel imprint (or wheels envelope).

In the formula (9.4.9), following *K* values shall be applied:

– $K = 1.0$ – for stiffeners of landing grounds on special platforms, landing ground on longitudinally stiffened decks in end parts of the ship, and on the decks stiffened transversally;
– $K = 1 - \dfrac{\sigma_o}{R_e}$ – for longitudinal stiffeners of the deck (landing ground) in the middle part of the ship, where σ_o is a stress from general hull bending, calculated for the bending moment $M = M_s + 0.59M_w$; M_s and M_w – see Chapter B/15.
– *K* determined by the linear interpolation – for longitudinal stiffeners of landing grounds on the decks located between the middle part and end parts of the ship's hull.

8.4.2.3 In the landing ground's areas designated for maneuvering or parking helicopters, the required section modulus of stiffeners shall be determined from the formula (9.4.2) for loads in maneuvering conditions and loads in parking conditions (see 8.2).

8.4.2.4 Transverse section area of the stiffener web in area designated for landing shall not be less than the area determined from the formula:

$$A_s = \frac{12.5Q_s}{\tau_{dop}}, \ [\text{cm}^2] \quad (8.4.2.4)$$

where:
Q_s – see 8.2, [kN]
$\tau_{dop} = 0.5Re$, [MPa].

8.4.2.5 Scantling of stiffeners in areas other than designated for landing, manoeuvering and parking shall be determined as for decks, e.g. according to requirements of Chapter B/8.

8.4.3 Girders and Pillars

8.4.3.1 Scantlings of girders and elements of the structure supporting landing grounds shall be determined on the basis of direct calculations, taking into account the requirements of Chapter B/14.

8.4.3.2 Strength of girders and elements of the structure supporting landing ground for loads determined acc. to 8.2, applying assumptions relating to loads from wheels, given in 8.4.1.1 and 8.4.1.2, shall be checked.

The following criterion shall be fulfilled:

$$\sigma_{zr} = \sqrt{\sigma^2 + 3\tau^2} \leq Re \quad (8.4.3.2)$$

where:
σ – normal stresses; for the longitudinal girders of the landing grounds on decks σ represents a sum of stresses from bending of the girders and stresses from the general bending of the hull with moment $M_s + 0.59M_w$ (M_s, M_w – see B/15);
τ – mean tangent stresses in girders' webs.

8.4.3.3 In load conditions, as in 8.4.3.2, critical stresses in compressed elements supporting landing grounds shall not be less than compressive stresses.

8.4.3.4 Strength of girders and elements of the structure supporting landing grounds in helicopters' maneuvering and parking conditions for loads required in 8.4.1.6 shall also be checked.

Icing, acc. to B/17.4, shall, if applicable, be taken into account

Values of permissible stresses given in B/14.4 shall be applied.

8.5 Plating, Stiffeners, Girders and Pillars of VERTREP Planes

8.5.1 Plating

8.5.1.1 If the pieces of cargo or equipment provided for lowering on the VERTREP plane are in a form of rigid elements, then assumption shall be made, that the load in lowering conditions is uniformly distributed over two areas with dimensions 0.1 m × 0.1 m, under any two corners of the element.

In the case of other types of cargo, loads in lowering conditions are subject of separate PRS consideration.

8.5.1.2 Plating of VERTREP planes shall be determined acc. to sub-chapter 8.4.1, as for plating of landing grounds decks, but for the substitute areas of the wheels imprint acc. to 8.5.1.1.

8.5.1.3 Plating shall also comply with the requirements of Chapter B/8, concerning decks.

8.5.2 Stiffeners

8.5.2.1 Scantlings of stiffeners shall be determined in accordance with the requirements of 8.4.2 for helicopters' landing grounds stiffeners (in an applicable scope), assuming loads acc. to 8.5.1.1.

8.5.3 Girders and Pillars

8.5.3.1 Scantlings of girders and pillars shall be determined acc. to requirements of 8.4.3 for helicopters' landing grounds (in an applicable scope), assuming loads acc. to 8.5.1.1.

9 DECKS FOR TRANSPORT OF VEHICLES

9.1 General

9.1.1 Application

Requirements of the present Chapter are applicable to the ships' decks, stiffened longitudinally or transversely, designated for transport of wheeled or tracked vehicles, as well as to decks of storing spaces, where vehicles are employed to handling of stores or cargoes.

9.1.2 Technical Documentation

9.1.2.1 Following data shall be submitted for PRS consideration and approval:
– arrangements plan of vehicles distribution on decks;
– assumed vehicles parameters, such as:
  – the maximum weight,
  – spacing of axis and wheels, or dimensions of wheels imprints and spacing of tracks,
  – type of tires and dimensions of tires' imprints,
  – static loads assigned to particular wheels or particular tracks' links.

9.1.2.2 Parameters required in 9.1.2.1 shall be recorded in *Loading Manual.*

9.2 Materials and Welding

9.2.1 Permanent fittings (permanently connected to the construction of the hull), for fixing vehicles and cargo, shall be made of steel having a category satisfying the requirements of Chapter B/2. Application of other categories of steel or other materials is subject to separate consideration by PRS.

9.2.2 Castings of permanent fittings, permanently connected to the hull structure, provided for fixing vehicles and cargoes shall satisfy requirements of *Part IX – Materials and Welding.*

9.2.3 Welding of permanent fitting elements for fixing of vehicles and cargoes to the hull structure, shall satisfy requirements of Chapter B/4.

9.2.4 At the connections of girders and stiffeners to plating of decks designated for transport of vehicles any cuts shall be avoided. In general double side continuous welding shall be applied. Double side intermittent welding may be applied upon separate consideration by PRS.

9.3 Plating

9.3.1 General

Strength requirements for plating of decks, which may be exposed to loads from the vehicles' wheels, are based on assumption that the plates are subject of uniform surface loading (pressure) from the single wheel.

In the case of wheels group, which imprints are spaced less than the smaller dimension of a single wheel imprint, when considering its effect on the plating it may be substituted by the imprint with dimensions of the wheels group envelope.

Scantling of the plating in case of other configuration of the wheels' group imprint is subject of separate PRS consideration.

9.3.2 Design Pressure and Dimensions of Wheel Imprint

9.3.2.1 Design pressure and dimensions of the wheels imprints (or wheels' group envelope) shall be determined on the basis of vehicles technical data (see 9.3.2.2).

If the distribution and dimensions of the wheels' imprints are not known, then, for the need of strength calculations they shall be determined acc. to 9.3.2.4.

9.3.2.2 Design area of the single wheel, or wheels' group, inprint F shall be determined from the formula:

$$F = u \cdot v, \ [\mathrm{m}^2] \qquad (9.3.2.2)$$

where: $v = v_1$ – for the single wheel, or when $e > v_1$ (Fig. 9.3.2.2); for the wheels group v acc. to Fig. 9.3.2.2.

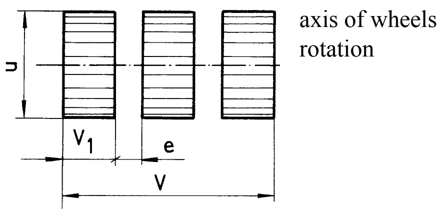


Fig. 9.3.2.2

9.3.2.3 If the dimensions u and v of wheel imprints are known (see 9.3.2.2), the static pressure p_k acting on the area of the wheel imprint shall be determined from the formula:

$$p_k = \frac{n}{n_0} \frac{Q_0}{F}, \ [\mathrm{kPa}] \qquad (9.3.2.3\text{-}1)$$

where:

n – number of wheels forming the group of wheels (for single wheel $n = 1$);

n_0 – number of wheels on the vehicle axis;

F – area of wheel, or wheels group, imprint, [m^2];

Q_0 – static load attributed to the axis, [kN];

In the case of unequal loads on particular vehicle axes, Q_0 shall be assumed such, that calculated p_k has the highest value.

The minimum value of Q_0 assumed for calculations shall correspond to the load of single wheel and amount to 3.0 kN.

In the case of forklifts employed in loading operations, assumption shall be made, that total weight of the vehicle with the load acts on the front axis.

In the case of tracked vehicles, F represents the area of track imprint, and Q_0 represents a half of the vehicle weight.

Design pressure p acting on the surface of the wheel imprint, necessary for the determination of design load Q, used for calculation of the required plating thickness (see 9.3.3.1 and 9.3.3.2), and section modulus of plating stiffeners (see 9.4.2 and 9.4.3) shall be determined from the formula:

$$p = K_d p_k \,, \text{ [kPa]} \qquad (9.3.2.3\text{-}2)$$

K_d = $\alpha_1 \cdot \alpha_2$ – factor taking into account dynamic loads from moving vehicles;

α_1 – factor equal to:

α_1 = 1.1 – in the case of vehicles (except of forklifts and track vehicles) with axis load less than 50 kN,

α_1 = 1.05 – in the case of vehicles (except of forklifts and track vehicles) with axis load of 50 kN or more,

α_1 = 1 – in the case of forklifts and track vehicles,

α_2 – factor equal to 1.15 – in the case of vehicles with pneumatic and solid tires, or 1.25 – in the case of vehicles with steel wheels (hoops) and track vehicles;

$K_d = 1 + \dfrac{0.5 a_v}{g}$ – in sea conditions;

a_v – vertical acceleration, [m/s^2], determined acc. to B/17.5.4.1;

9.3.2.4 If the dimensions of the wheels' imprints are not known, the pressure p_k, [kPa], may be adopted from the Table 9.3.2.4

Table 9.3.2.4

Type of vehicle	Type of tires	
	pneumatic	solid
Personal and cross-country vehicles	200	–
Trucks, lorries	800	–
Trailers and semi-trailers	800	1500
Forklifts	800 (for n = 1)	1500
	600 (for $n \geq 2$)	1500

The area of the wheel, or wheels' group, imprint shall be determined from the formula:

$$F = \frac{n}{n_0}\frac{Q_0}{p_K}, \quad [\mathrm{m}^2] \qquad (9.3.2.4\text{-}1)$$

n, n_0, Q_0 – as in 9.3.2.3.

Imprint dimension u, perpendicular to the wheels axis of rotation, shall be determined from the formula (see Fig. 9.3.2.2):

– for wheels with solid tires:

$$u = 0.1\frac{Q_0}{n_0}, \quad [\mathrm{m}], \quad \text{where} \quad \frac{Q_0}{n_0} \le 15\ \mathrm{kN}, \qquad (9.3.2.4\text{-}2)$$

$$u = 0.15 + 0.001\left(\frac{Q_0}{n_0} - 100\right), \quad [\mathrm{m}], \quad \text{where} \quad \frac{Q_0}{n_0} > 15\ \mathrm{kN},$$

– for wheels with pneumatic tires:

$$u = 0.15 + 0.0025\frac{Q_0}{n_0}, \quad [\mathrm{m}], \quad \text{where} \quad \frac{Q_0}{n_0} \le 100\ \mathrm{kN}, \qquad (9.3.2.4\text{-}3)$$

$$u = 0.4 + 0.002\left(\frac{Q_0}{n_0} - 100\right), \quad [\mathrm{m}], \quad \text{where} \quad \frac{Q_0}{n_0} > 100\ \mathrm{kN}.$$

Wheel, or wheels group, imprint dimension v, parallel to the wheels axis of rotation, shall be determined from the formula:

$$v = \frac{F}{u}, \quad [\mathrm{m}] \qquad (9.3.2.4\text{-}4)$$

9.3.2.5 At establishing design loads, in-port loads (loading operations) and sea loads from the carried vehicles, shall be considered.

Design loads shall be determined for two, mutually perpendicular positions of the wheels' axis of rotation against sides of the plating or stiffeners:

– wheels rotation axis parallel to the shorter side of the plate (perpendicular to stiffeners direction),
– wheels rotation axis parallel to the longer side of the plate (parallel to stiffeners direction).

In all cases wheels imprints shall be situated in such manner, that the longer side of the plate, or segment of the plating supported by stiffener, are loaded at the greatest length.

9.3.3 Required Plating Thickness

9.3.3.1 Thickness of the deck plating exposed to wheels loads shall not be less, than thickness determined from the formula:

$$t = 58K_1\sqrt{\frac{K_2 Q s}{mR_e}} + t_k, \quad [\mathrm{mm}] \qquad (9.3.3.1)$$

K_1 – numerical factor, the value of which shall be determined in the following way:
– the minimum values of K_1, which may be applied for the plating of all decks, except of the upper deck, are:
$K_1 = K_{1min} = 1.0$ – for in-port conditions, for loads during loading operations,
$K_1 = K_{1min} = 1.075$ – for at-sea conditions, for loads from carried vehicles;
– For the upper deck in a midship part of the ship:

$$K_1 = \frac{1}{\sqrt{K_0}}$$

but not less than K_{1min} values given above.
Values of K_0 factor shall be adopted according to Table 9.3.3.1.

Table 9.3.3.1
K_0 Values

Deck stiffening system	Service conditions	
	In-port	At-sea
longitudinal	$K_0=1-0.05\frac{W}{W_r}$	$K_0=0.92-0.16\frac{W}{W_r}$
transverse	$K_0=1-0.23\frac{W}{W_r}$	$K_0=0.86-0.36\frac{W}{W_r}$

W – required section modulus of the hull in the ships' middle part, [cm^3], determined acc. to B/15.2.1;
W_r – actual section modulus of the hull in the ships' middle part, [cm^3], determined acc. to principles given in B/15.7.1;
– for the upper deck plating in terminal parts of the ship, minimum values of K_1 given above are obligatory;
– between middle part of the ship and its terminal parts, K_0 values change linearly;

$K_2 = 1.25 - 0.5\frac{s}{l}$ for $\frac{s}{l} > 0.5$,

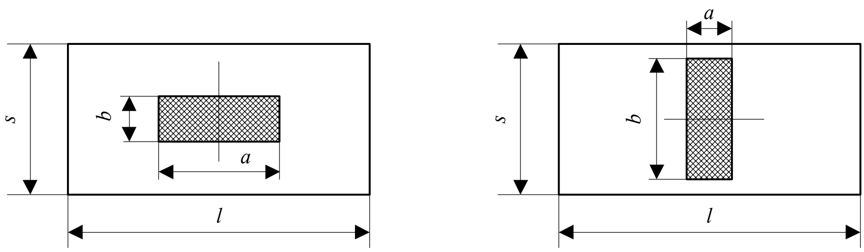
$K_2 = 1$ for $\frac{s}{l} \le 0.5$;
l – span of the beams, [m];
s – beams spacing, [m];
Q – design load, determined acc. to 9.3.4;
R_e – yield point of the plating material, [MPa] (see B/2.2);
m – factor, calculated as follows (for the imprint of single wheel or wheels group envelope) – see Fig. 9.3.3.1):

$$m = \frac{5.85}{1-0.57\frac{b}{s}} \quad \text{dla} \quad \frac{b}{s} < 1,$$

$$m = 29.47 - \frac{b}{s}\left[23.65 - 8.75\frac{b}{s} + 0.97\left(\frac{b}{s}\right)^2\right] \quad \text{for} \quad 1 \le \left(\frac{b}{s}\right) \le 3.35,$$

m = 12 for $\frac{b}{s} > 3.35$,

b – length of the wheel imprint edge perpendicular to stiffeners (Fig. 9.3.3.1), [m];



a) axis of wheels rotation perpendicular to stiffeners

b) axis of wheels rotation parallel to stiffeners

Fig. 9.3.3.1

9.3.3.2 If the wheel imprint dimensions are determined acc. to 9.3.2.4, plating thickness determined acc. to 9.3.3.1 shall be increased by 15%.

9.3.3.3 Plating thickness determined acc. to 9.3.2.4 for the loads from track vehicles shall additionally be increased by 1.5 mm.

9.3.3.4 Deck plating thickness shall not be less than determined acc. to B/8.3 for decks in storage spaces.

9.3.4 Design Load for Plating

Design load for plating, Q, [kN], shall be determined from the formula:

$$Q = p\,C\,s_1\,, \ \text{[kN]} \qquad (9.3.4)$$

where:

p – acc. to formula 9.3.2.3-2;

$C = 1.35C_1 - 0.6C_1^2 + 0.09C_1^3$, but not more than 1;

$C_1 = \frac{a}{s}$;

a, s – acc. to Fig. 9.3.3.1;

$s_1 = b$, when $b < s$;

$s_1 = s$, when $b \ge s$;

b – acc. to Fig. 9.3.3.1.

9.4 Beams

9.4.1 General

When establishing design loads for beams, the principles for plating provided in 9.3.2.5 shall be applied.

9.4.2 Beams Section Modulus

Net section modulus (e.g. after subtraction of corrosion allowances acc. to B/2.5) transverse and longitudinal beams of decks subject to loads from wheels shall not be less, than modulus determined from the formula:

$$W = \frac{1000\,Ql}{mKR_e} \quad [\text{cm}^3] \qquad (9.4.2)$$

Q – design load, [kN], determined acc. to 9.4.3;
l – beam span, [m];
R_e – yield point of beam material, [MPa];
m – factor, determined as follows:

$$m = \frac{5.85}{1 - 0.57\frac{a}{l}} \quad \text{for } \frac{a}{l} < 1,$$

$$m = 29.47 - \frac{a}{l}\left[23.65 - 8.75\frac{a}{l} + 0.97\left(\frac{a}{l}\right)^2\right] \quad \text{for } 1 \le \left(\frac{a}{l}\right) \le 3.35,$$

$$m = 12 \text{ for } \frac{a}{l} > 3.35;$$

a – dimension of the imprint along stiffeners – see Fig. 9.3.3.1;

K – factor of the permissible stresses, with values determined in the following way:
- for longitudinal beams in the midship part of the ship – acc. to Table 9.4.2, whereas adopted values shall not exceed K_{max};
- for longitudinal beams in the end parts of the ship: $K = K_{max}$; between the midship and end parts of the ship K value varies linearly;
- for transverse beams: $K = K_{max}$.

W – required value of the hull section modulus in the middle part of the ship, [cm^3], determined acc. to B/15.2.1;
W_r – actual value of the hull section modulus for the considered section in the middle part of the ship, [cm^3], determined acc. to principles provided in B/15.7.1.

Table 9.4.2
***K* values for longitudinal beams in the middle part of the ship**

Longitudinal beams	Service conditions	
	At-sea	In-port
Any deck	$0.96 - 0.56\frac{W}{W_r}$	$0.96 - 0.36\frac{W}{W_r}$
K_{max}	0.7	0.8

9.4.3 Design Loads

Design loads for stiffeners Q shall be determined from the formula:

$$Q = K \cdot p \cdot s_1 \cdot l_1, \text{ [kN]}$$

where:

$K = 1$, when $\frac{b}{s} < 1$ or $\frac{b}{s} \geq 3$

$K = 1.3 - 0.3\left(\frac{b}{s} - 2\right)$, when $1 \leq \frac{b}{s} < 3$

s – width of the plating strip supported by the stiffener (stiffeners spacing), [m];
p – design pressure determined acc. to formula (9.3.2.3-2);
$s_1 = b$, when $b < s$,
$s_1 = s$, when $b \geq s$,
$l_1 = a$, when $a < l$,
$l_1 = l$, when $a \geq l$,
a, b, s, l – see Fig. 9.3.3.1.

9.4.4 Additional Requirements for Beams Section Modulus

9.4.4.1 If the wheels' imprint dimensions are determined acc. to 9.3.2.4, the section modulus determined acc. to formula (9.4.2), shall be increased by 15%.

9.4.4.2 In situations, where beams cannot be considered as rigidly supported on each girder, values of factor *m* shall be agreed with PRS.

9.4.4.3 Beams' section modulus shall not be less from required for storage spaces, for loads acc. to B/17.6.7.

9.5 Girders

9.5.1 Method of Girders Strength

Scantlings of girders are subject of checking by methods of zone strength analysis provided in B/14.

Values of permissible stresses are provided in B/14.5.

9.5.2 Load

The calculation shall take into account the most adverse variations in vehicle loads in port and at-sea conditions, having regard to the dynamic loads in the same way as described in section 9.3.2.3 on plating loads.

The strength of girders shall be adequate also for the minimum pressures, with values provided in B/17.6.7, acting on the entire surface of the deck.

10 ICE STRENGTHENINGS

10.1 General

10.1.1 Application

10.1.1.1 The requirements of the present chapter apply to ships intended for navigation in waters with ice conditions.

10.1.1.2 The requirements specified in this Chapter shall be regarded as supplementary to the basic ones specified Part B.

10.1.2 Classification

10.1.2.1 Vessels built in accordance with the requirements specified in sub-chapter 10.2 applicable to ships intended for occasional navigation in light ice conditions (in fine ice pieces) in coastal areas of the western part of the Baltic Sea or in other areas with similar ice conditions may be affixed with the ice strengthening mark (**L4)**.

10.1.2.2 Vessels built in accordance with the requirements specified in sub-chapter 10.3 applicable to ships intended for navigation in winter in the Baltic Sea or other non-Arctic seas with similar ice conditions may be affixed with the following ice strengthening marks, depending on strengthening applied:
- **L3**, for navigation in light ice conditions,
- **L2**, for navigation in medium ice conditions,
- **L1**, **L1A** for navigation in heavy ice conditions.

The decision on necessity to provide ice strengthening in ship rests with the Owner.

10.1.2.3 Ice strengthening for ships intended for navigation in Arctic seas are subject to PRS acceptance in each particular case.

10.1.3 Definitions

L_0 – design length of the ship, as defined in A/2.2, [m];
s_s – standard frame spacing, [m];
$s_s = 0.48 + 0.002\ L_0$;
$s_s \leq 0.61$ m shall be taken forward of the collision bulkhead;
s_0 – real frame spacing, not including intermediate frames, [m];
s – frame spacing, including intermediate frames, if applied, measured along the shell plating, [m];
l – span of stiffener or girder, measured along the flange, [m];
D_s – ship displacement in fresh water (ρ = 1.0 t/m^3) at maximum ice class draught amidships, as specified in 10.1.4, [t];
N_s – the actual continuous engine output of the ship, [kW],
LWL – maximum draught line – the line defined on side plating by the maximum draughts fore, amidships and aft (may be a broken line).

BWL – ballast line – the line defined on side plating by the minimum draughts fore and aft,

R_e – material yield point – see paragraph B/2.2, [MPa].

10.1.4 Explanations

Maximum ice class draught amidships – the draught corresponding to the maximum permissible draught.

Ice belt – the part of the shell plating which shall be reinforced.

Ice belt regions – for ice classes **L1A**, **L1**, **L2** and **L3** the ice belt is subdivided into the following regions (see Fig. 10.1.4):

Forward region – from the stem to a line parallel to and 0.04 L_0 aft of the forward borderline of the part of the hull where the waterlines run parallel to the centre plane; the overlap over the borderline need not exceed 6 m for ice classes **L1A** and **L1**, and 5 m for **L2** and **L3**.

Midship region – from the aft boundary of the forward region to a line parallel to and $0.04L_0$ aft of the aft borderline of the part of the hull where the waterlines run parallel to the centre plane; the overlap over the borderline need not exceed 6 m for ice classes **L1A** and **L1**, and 5 m for **L2** and **L3**.

Aft region – ice belt part from the aft boundary of the midship region to the stern.

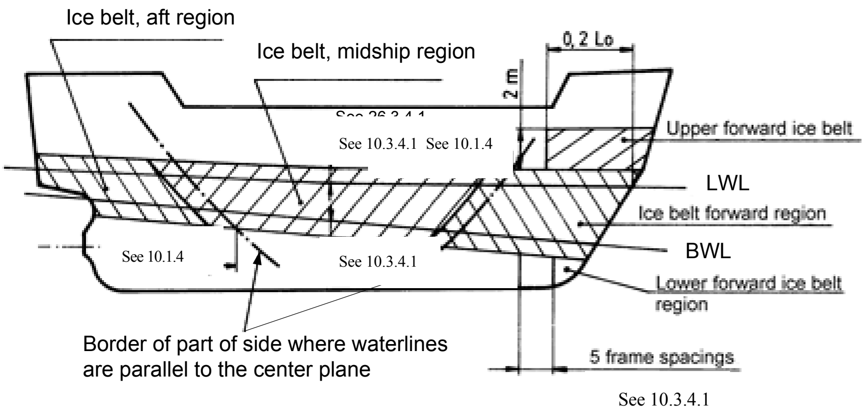


Fig. 10.1.4 Ice belt regions

10.2 Basic Ice Strengthening (L4)

10.2.1 Ice Belt

10.2.1.1 The ice belt shall extend vertically from 0.5 m above LWL to 0.5 m below BWL.

10.2.1.2 In the fore part of the ship, from stem to cross-section $x = (0.5\ L_0 - B)$, the shell plating thickness shall not be less than:

$$t = 6 + 0.11L_0 + \Delta t, \quad \text{[mm]} \qquad (10.2.1.2)$$

$\Delta t = 20\,(s_0 - s_s)$, [mm]; $\Delta t \geq 0$ shall be taken.

From the section $x = (0.5\,L_0 - B)$ to the position where the waterlines reach their full breadth, the shell plating thickness of ice belt shall be gradually reduced to the normal thickness. The shell plating thickness need not exceed 25 mm.

10.2.2 Frames

10.2.2.1 Section modulus of the frames in the fore peak shall not be less than:

$$W = 0.25 L_0 T, \quad [\text{cm}^3] \qquad (10.2.2.1)$$

Spacing of the frames in fore peak shall not exceed 0.61 m.

10.2.2.2 Section modulus of the frames within the region from the fore peak bulkhead to the section $x = 0.5\,L_0 - 1.5\,B$ shall not be less than:

$$W = 0.4 s_0 L_0 T, \quad [\text{cm}^3] \qquad (10.2.2.2)$$

10.2.3 Intermediate Frames

10.2.3.1 Intermediate frames shall be fitted within the region from stem to the section positioned 1.5 *B* from *FP* abaft.

Upper ends of intermediate frames shall extend 0.62 m above *LWL* and the lower ends – not less than 1.0 m below *BWL*.

Additional stiffeners between bottom floors shall be fitted where any part of the bottom is situated less than 0.5 m below *BWL*.

10.2.3.2 Intermediate frames may be omitted if the spacing of frames does not exceed:

0.37 m forward of collision bulkhead,

$0.288 + 0.0012\,L_0$, [m], not more, however, than 0.42 m abaft the collision bulkhead.

10.2.3.3 Section modulus of the intermediate frames abaft the collision bulkhead shall not be less than:

$$W = \left(\frac{L_0^2}{100} + 20\right)\frac{s_0}{s_s}, \quad [\text{cm}^3] \qquad (10.2.3.3\text{-}1)$$

Section modulus of the intermediate frames forward of collision bulkhead shall not be less than:

$$W = \left(\frac{L_0^2}{160} + 10\right)\frac{s_0}{s_s}, \quad [\text{cm}^3] \qquad (10.2.3.3\text{-}2)$$

Where the span of intermediate frames forward of the collision bulkhead is different from 2 m, the value of the required section modulus shall be modified in direct proportion. Intermediate frames need in no case have a section modulus larger than 75% of that of main frames within the same region.

10.2.3.4 The ends of intermediate frames shall be connected to horizontal carlings between main frames. These carlings shall not form a continuous stringer. Where intermediate frames extend to a deck, the upper carlings may be omitted.

10.2.4 Ice Stringer

In single deck ships, an ice stringer shall be fitted 0.2 to 0.3 m below *LWL* from the stem to the section $x = 0.5\ L_0 - 2\ B$.

Forward of the collision bulkhead, the shape and scantlings of ice stringer shall be the same as those of an ordinary girder on the ship's side. Beyond the fore peak the ice stringer shall consist of a series of tripping brackets fitted to the frames.

10.2.5 Welding

In way of fore peak, tee joints connections of structural parts with the shell plating shall be continuous and double sided.

10.2.6 Stern Frame Section Moduli

Section moduli of the stern frame, rudder horn shall be by 7.5% greater than those required in Chapter B/11.

10.3 Ice Strengthenings L1A, L1, L2 and L3

10.3.1 General Requirements

10.3.1.1 The requirements for ice strengthening of the hull structure are related to:

- the thickness of side plating in various ice belt regions (see sub-chapter 10.3.4.2), the vertical extension of the ice belt shall fulfil the requirements specified in sub-chapter 10.3.4.1,
- the scantlings of frames and intermediate frames supporting the ice belt plating (see sub-chapter 10.3.5.2 – for transverse frames, and sub-chapter 10.3.5.3 – for longitudinal framing; the vertical extension of the ice strengthened framing shall fulfil the requirements specified in sub-chapter 10.3.5.1),
- the scantlings of side stringer elements (see sub-chapters 10.3.6.1 and 10.3.6.2),
- the scantlings of web frames (see sub-chapter 10.3.7),
- material and structure of stem (see sub-chapter 10.3.8.1),
- strengthening of after part structure (see sub-chapter 10.3.9).

10.3.1.2 Instead of the formulae and values specified in sub-chapter 10.3 for the determination of the hull scantlings more sophisticated methods may be used.

Results of such calculations and the theoretical background shall be submitted to PRS.

If the scantlings derived from the requirements specified in the present Chapter are less than those required for an unstrengthened ship, the latter shall be used.

10.3.1.3 The maximum and minimum ice class draughts fore and aft shall be determined and they are stated in the *Certificate of Class*.

The ship draught and trim, limited by the *LWL* (see sub-chapter 10.1.3), must not be exceeded when the ship is navigating in ice. The sea water salinity along the intended route shall be taken into account when loading the ship.

The ship shall always be loaded down at least to the BWL when navigating in ice.

Any ballast tank, situated above the *BWL* (see sub-chapter 10.1.3) and needed to load down the ship to this waterline shall be equipped with devices preventing water from freezing. In determining the BWL, regard shall be paid to the need for ensuring a reasonable degree of ice-going capability in ballast. The propeller shall be fully submerged, if possible, entirely below the ice.

The minimum forward draught shall not be less than that determined in accordance with the following formula:

$$T_1 = (2 + 0.00025 D_s) h_0, \text{ [m] but need not exceed } 4\, h_0 \qquad (10.3.1.3)$$

D_s – see 10.1.3;
h_0 – level ice thickness determined in accordance with sub-chapter 10.3.3.

10.3.2 Documentation

10.3.2.1 The classification documentation submitted to PRS shall cover details related to ice classes in respect of design, arrangement and strength.

10.3.2.2 In the shell expansion drawing, lines separating the forward, midship and aft regions of the ice belt, *LWL* and *BWL*, as well as the upper and lower boundaries of minimum extension of frames strengthened for ice conditions shall be indicated.

The displacement D_s and maximum continuous power N_s shall be indicated on the drawings of midship section and shell expansion.

10.3.3 Ice Load

10.3.3.1 Height of Load Area

An ice strengthened ship is assumed to operate in open sea conditions corresponding to a level ice thickness not exceeding h_0. The design height h of the area actually under ice pressure at any particular point of time is, however, assumed to be only a fraction of the ice thickness h_0.

The values for h_0 and h are specified in Table 10.3.3.1.

Table 10.3.3.1

Ice class	h_0 [m]	h [m]
L1A	1.0	0.35
L1	0.8	0.30
L2	0.6	0.25
L3	0.4	0.22

10.3.3.2 Design Ice Pressure

Design ice pressure shall be determined in accordance with the following formula:

$$p = c_a c_b c_c p_0, \quad \text{[MPa]} \qquad (10.3.3.2\text{-}1)$$

p_0 – the nominal ice pressure; the value p_0 = 5.6 MPa shall be used;

c_a – factor which takes account of the influence of the size and engine output of the ship, to be determined in accordance with the following formula:

$$c_a = \frac{ak_1 + b}{1{,}000};$$

$$k_1 = \frac{\sqrt{D_s N_s}}{1{,}000};$$

a, b – parameters specified in Table 10.3.3.2-1.

Table 10.3.3.2-1

Parameters	Ice belt region			
	Forward		Midship and Aft	
	$k_1 \le 12$	$k_1 > 12$	$k_1 \le 12$	$k_1 > 12$
a	30	6	8	2
b	230	518	214	286

D_s, N_s – see sub-chapter 10.1.3;

c_b – factor which takes account of the probability that the design ice pressure occurs in a certain region of the hull for the ice class in question; the values of c_b shall be taken from Table 10.3.3.2-2;

Table 10.3.3.2-2

Ice Class	Ice belt region		
	Forward	Midship	Aft
L1A	1.0	1.0	0.75
L1	1.0	0.85	0.65
L2	1.0	0.70	0.45
L3	1.0	0.50	0.25

c_c – factor which takes account of the probability that the full length of the area under consideration will be under pressure at the same time; the values of c_c shall be determined in accordance with the following formula:

$$c_c = \frac{47 - 5l_a}{44} \qquad (10.3.3.2\text{-}2)$$

$0.6 \le c_c \le 1.0$ shall be taken;

l_a – parameter determined in accordance with Table 10.3.3.2-3.

Table 10.3.3.2-3

Structure	Type of framing	l_a [m]
Shell	transverse	frame spacing
	longitudinal	2 × frame spacing
Frames	transverse	frame spacing
	longitudinal	span of frame
Ice stringer	–	span of stringer
Web frame	–	2 x web frame spacing

10.3.4 Shell Plating

10.3.4.1 Vertical Extension of the Ice Strengthening (Ice Belt)

The required vertical extension of the ice strengthening is shown on Fig. 10.1.4.

The vertical extension of the ice belt shall not be less than that specified in Table 10.3.4.1.

Table 10.3.4.1

Ice Class	Above *LWL*, [m]	Below *BWL*, [m]
L1A	0.6	0.75
L1	0.5	0.6
L2	0.4	0.5
L3	0.4	0.5

In addition, the following areas shall be strengthened:

Fore foot (see Fig. 10.1.4): For ice class **L1A**, the shell plating below the ice belt from the stem to a position five main frame spaces abaft the point where the bow profile departs from the keel line shall have at least the thickness required in the ice belt in the midship region.

Upper forward ice belt (see Fig. 10.1.4): For ice classes **L1A**, and **L1** on ships with an open water service speed equal to or exceeding 18 knots, the shell plate from the upper limit of the ice belt to 2 m above it and from the stem to a position at least $0.2L_0$ abaft the forward perpendicular, shall have at least the thickness required in the ice belt in the midship region. A similar strengthening of the bow region is advisable also for a ship with a lower service speed, when it is, e.g. on the basis of the model tests, evident that the ship will have a high bow wave.

Sidescuttles shall not be situated in the ice belt. If the weather deck in any part of the ship is situated below the upper limit of the ice belt (e.g. in way of the well of a raised quarter decker), the bulwark shall be given at least the same strength as is required for the shell in the ice belt. The strength of the construction of the freeing ports shall meet the same requirements.

10.3.4.2 Plate Thickness in the Ice Belt

For transverse framing, required shell plating thickness in the ice belt shall be determined in accordance with the following formula:

$$t = 667\,s\sqrt{\frac{c_1 p_1}{R_e}} + t_c, \quad [\text{mm}] \qquad (10.3.4.2\text{-}1)$$

For longitudinal framing, required shell plating thickness shall be determined in accordance with the following formula:

$$t = 667s\sqrt{\frac{p_1}{c_2 R_e}} + t_c, \quad [\text{mm}] \qquad (10.3.4.2\text{-}2)$$

p_1 = 0.75 p (p – see formula 10.3.3.2-1), [MPa];

$c_1 = 1.3 - \frac{4.2}{\left(\frac{h}{s} + 1.8\right)^2}$, but not greater than 1.0;

$c_2 = 0.6 + \frac{0.4}{\frac{h}{s}}$ if $\frac{h}{s} \le 1$,

$c_2 = 1.4 - 0.4\frac{h}{s}$ if $1 < \frac{h}{s} < 1.8$,

h – see sub-chapter 10.3.3.1;

t_c – allowance for abrasion and corrosion, [mm]; normally t_c = 2 mm. If a special surface coating, by experience shown capable to withstand the abrasion of ice, is applied and maintained, lower values may be permitted by PRS.

10.3.5 Frames

10.3.5.1 Vertical Extension of Ice Strengthening

The vertical extension of the ice strengthening of the framing shall not be less than that specified in Table 10.3.5.1.

Table 10.3.5.1

Ice Class	Region	Above *LWL*, [m]	Below *BWL*, [m]
L1A	from stem to 0.3 L_0 abaft it	1.2	To double bottom or below top of floors
	abaft 0.3 L_0 from stem	1.2	1.6
	midship	1.2	1.6
	aft	1.2	1.2
L1, L2, L3	from stem to 0.3 L_0 abaft it	1.0	1.6
	abaft 0.3 L_0 from stem	1.0	1.3
	midship	1.0	1.3
	aft	1.0	1.0

Where an upper forward ice belt is required (see sub-chapter 10.3.4.1), the ice-strengthened part of the framing shall be extended at least to the top of this ice belt.

Where the ice strengthening would go beyond a deck or a tanktop by not more than 250 mm, it can be terminated at these constructions.

10.3.5.2 Transverse Frames

10.3.5.2.1 Section Modulus

The section moduli of main and intermediate transverse frames shall be determined in accordance with the following formula:

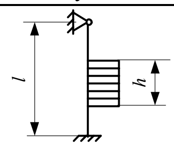
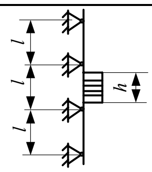
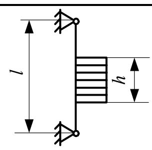
$$W = \frac{pshl}{m_t R_e} 10^6, \quad [\text{cm}^3] \qquad (10.3.5.2.1)$$

p – ice pressure, [MPa], determined in accordance with sub-chapter 10.3.3.2;
h – height of load area, [m], determined in accordance with sub-chapter 10.3.3.1;
l – span of the frame, [m];

$$m_t = \frac{7m_0}{7 - 5\frac{h}{l}};$$

m_0 – factor determined in accordance with Table 10.3.5.2.1.

Table 10.3.5.2.1

Boundary condition	m_0	Example
	6	Frames extending from the tanktop to a single deck
	5.7	Continuous frames between several decks or side stringers
	5	Side frames extending between two decks only

The boundary conditions are those for the main and intermediate frames. Load is applied at mid span.

Where less than 15% of the span, l, of the frame is situated within the ice-strengthening zone for frames (see 10.3.5.1), ordinary frame scantlings may be used.

10.3.5.2.2 Upper End of Transverse Framing

The upper end of the strengthened part of a main frame and of an intermediate ice frame shall be attached to a deck or an ice stringer (see 10.3.6).

Where a frame terminates above a deck or a stringer which is situated at or above the upper limit of the ice belt (see 10.3.4.1), the part above the deck or stringer may have the scantlings required for an unstrengthened ship and the upper end of an intermediate frame may be connected to the adjacent frames by a horizontal member having the same scantlings as the main frame. Such an intermediate frame can also be extended to the deck above and if this is situated more than 1.8 metre above the ice belt, the intermediate frame need not be attached to that deck, except in the forward region.

10.3.5.2.3 Lower End of Transverse Framing

The lower end of the strengthened part of a main frame and of an intermediate ice frame shall be attached to a deck, tanktop or ice stringer (see sub-chapter 10.3.6).

Where an intermediate frame terminates below a deck, tanktop or ice stringer which is situated at or below the lower limit of the ice belt (see sub-chapter 10.3.4.1), the lower end may be connected to the adjacent main frames by a horizontal member of the same scantlings as the frames.

10.3.5.3 Longitudinal Frames

The section modulus of a longitudinal frame shall be determined from the following formula:

$$W = \frac{c_3 c_4 p h l^2}{m_1 R_e} 10^6, \quad [\text{cm}^3] \qquad (10.3.5.3\text{-}1)$$

The shear area of a longitudinal frame shall be determined in accordance with the formula:

$$A = \frac{\sqrt{3}\ c_3 p h l}{2 R_e} 10^4, \quad [\text{cm}^2] \qquad (10.3.5.3\text{-}2)$$

The above formulae are valid only if the longitudinal frame is attached to supporting structure by brackets as required in paragraph 10.3.5.4.1.

c_3 – factor which takes account of the load distribution to adjacent frames;

c_3 = $1 - 0.2\frac{h}{s}$;

s – frame spacing, [m]; the frame spacing shall not exceed 0.35 m for ice class **L1A** or **L1** and in no case shall exceed 0.45;

l – span of frame, [m];

c_4 – factor which takes account of the concentration of load at the point of support; $c_4 = 0.6$ shall be taken;

p – ice pressure, [MPa], as specified in sub-chapter 10.3.3.2;
h – height of load area as specified in sub-chapter 10.3.3.1;
m_1 – boundary condition factor; m_1 = 13.3 for a continuous beam; smaller factors may be required where the boundary conditions deviate considerably from those of a continuous beam; e.g. in an end field.

10.3.5.4 General Requirements for Framing

10.3.5.4.1 Within the ice-strengthened area all frames shall be effectively attached to all the supporting structures. A longitudinal frame shall be attached to all the supporting web frames and bulkheads by brackets. When a transversal frame terminates at a stringer or deck, a bracket or similar construction shall be fitted. When a frame is running through the supporting structure, both sides of the web plate of the frame shall be connected to the structure (by direct welding, collar plate or lug). When a bracket is installed, it has to have at least the same thickness as the web plate of the frame and the edge has to be appropriately stiffened against buckling.

10.3.5.4.2 In ships with ice classes:
L1A – within all regions,
L1 – in the midship and forward regions,
L2 and **L3** – in the forward region
the following shall apply in the ice-strengthened area:

– frames which are not at straight angle to the shell shall be supported by tripping brackets, intercostals, stringers or similar at a distance not exceeding 1.3 m;
– the frames shall be attached to the shell by double continuous welds. No scalloping is allowed (except when crossing shell plate butts);
– the web thickness of the frames shall be at least one half of the thickness of the shell plating and at least 9 mm. Where there is a deck, tanktop or bulkhead in lieu of a frame, the plate thickness of this shall be as above, to a depth corresponding to the height of adjacent frames.

10.3.6 Ice Stringers

10.3.6.1 Stringers within the Ice Belt

Section modulus of a side stringer situated within the ice belt (see sub-chapter 10.3.4.1) shall be determined in accordance with the following formula:

$$W = \frac{c_5 p h l^2}{m_1 R_e} 10^6, \quad [\text{cm}^3] \qquad (10.3.6.1\text{-}1)$$

Shear area of the stringer shall not be less than that determined in accordance with the following formula:

$$A = \frac{\sqrt{3}\, c_5 phl}{2R_e} 10^4, \quad [\text{cm}^2] \qquad (10.3.6.1\text{-}2)$$

p – ice pressure, [MPa], as specified in sub-chapter 10.3.3.2;
h – height of load area, [m], as specified in sub-chapter 10.3.3.1; $ph \geq 0.3$ shall be taken;
l – stringer span, [m];
m_1 – stringer boundary condition factor (see sub-chapter 10.3.5.3)
c_5 – factor which takes account of the distribution of load to transverse frames; to be taken as 0.9.

10.3.6.2 Stringers outside the Ice Belt

Section modulus of a side stringer outside the ice belt but supporting ice strengthened frames shall be determined in accordance with the following formula:

$$W = \frac{c_6 phl^2}{m_1 R_e}\left(1 - \frac{h_s}{l_s}\right) 10^6, \quad [\text{cm}^3] \qquad (10.3.6.2\text{-}1)$$

Shear area of the stringer shall not be less than that determined in accordance with the formula:

$$A = \frac{\sqrt{3}\, c_6 phl}{2R_e}\left(1 - \frac{h_s}{l_s}\right) \cdot 10^4, \quad [\text{cm}^2] \qquad (10.3.6.2\text{-}2)$$

h_s – the distance to the ice belt, [m];
l_s – the distance to the adjacent ice stringer, [m];
p, h, l, m_1 – see sub-chapter 10.3.6.1;
c_6 – factor which takes account of load to the transverse frames; to be taken as 0.95.

The product $p \cdot h$ shall not be taken as less than 0.3.

10.3.6.3 Deck Strips

10.3.6.3.1 Narrow deck strips abreast of hatches and serving as ice stringers shall comply with the section modulus and shear area requirements specified in sub-chapter 10.3.6.1 or 10.3.6.2 respectively. In the case of very long hatches PRS may permit the product ph to be taken as less than 0.30 but in no case as less than 0.20.

10.3.6.3.2 When designing weather deck hatch covers and their fittings, regard shall be paid to the deflection of the ship sides due to ice pressure in way of very long hatch openings.

10.3.7 Web Frames

10.3.7.1 Load

The load transferred to a web frame from an ice stringer or from longitudinal framing shall be calculated in accordance with the following formula:

$$F = phS\,, \quad [\text{MN}] \qquad (10.3.7.1)$$

p – ice pressure as determined in sub-chapter 10.3.3.2, [MPa]; in calculating c_c however, l_a shall be taken as $2S$;
h – height of load area as determined in sub-chapter 10.3.3.1; $p\,h \ge 0.3$ shall be taken;
S – web frames spacing, [m].

If the supported stringer is outside the ice belt, the value of load F shall be multiplied by:

$$\left(1 - \frac{h_s}{l_s}\right)$$

where:
h_s, l_s – see sub-chapter 10.3.6.2.

10.3.7.2 Section Modulus and Shear Area

10.3.7.2.1 For a web frame simply supported at the upper end and fixed at the lower end (see Fig. 10.3.7.2.1), the section modulus shall be determined in accordance with the formula:

$$W = \frac{M}{R_e}\sqrt{\frac{1}{1-\left(c\dfrac{A}{A_a}\right)^2}}\,10^6\,, \quad [\text{cm}^3] \qquad (10.3.7.2.1\text{-}1)$$

M – maximum calculated bending moment under the load F, as specified in sub-chapter 10.3.7.1 or $k_1 \cdot F \cdot l$;

$$k_1 = \frac{1}{2}\left(\frac{l_f}{l}\right)^3 - \frac{3}{2}\left(\frac{l_f}{l}\right)^2 + \frac{l_f}{l} \qquad (10.3.7.2.1\text{-}2)$$

c – coefficient specified in Table 10.3.7.2.2;
A – required shear cross-sectional area of the web frame determined in accordance with formula 10.3.7.2.2-1 for factor k_2 determined in accordance with formula 10.3.7.2.2-2, [cm^2];
A_a – actual shear cross sectional area of the web frame, [cm^2];
l_f – distance from the lower support of the web frame to the stringer or longitudinal in question, [m]; for the lower part of the web frame, the smallest l_f within the ice belt shall be used; for the upper part, the biggest l_f within the ice belt shall be taken;
l – span of web frame, [m].

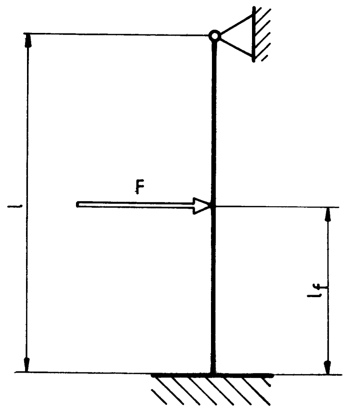


Fig. 10.3.7.2.1 Web frame

10.3.7.2.2 With boundary conditions as specified in paragraph 10.3.7.2.1, the shear area of the web frame shall be determined in accordance with the following formula:

$$A = \frac{\sqrt{3}\, eQ}{R_e} \cdot 10^4, \quad [\text{cm}^2] \qquad (10.3.7.2.2\text{-}1)$$

where:

Q – maximum calculated shear force under the load F (see sub-chapter 10.3.7.1), or $Q = k_2 \cdot F$;

$$k_2 = 1 + \frac{1}{2}\left(\frac{l_f}{l}\right)^3 - \frac{3}{2}\left(\frac{l_f}{l}\right)^2 \qquad (10.3.7.2.2\text{-}2)$$

or

$$k_2 = \frac{3}{2}\left(\frac{l_f}{l}\right)^2 - \frac{1}{2}\left(\frac{l_f}{l}\right)^3 \qquad (10.3.7.2.2\text{-}3)$$

whichever is the greater;

l_f, F, l – see paragraph 10.3.7.2.1;

e – factor specified in Table 10.3.7.2.2.

Table 10.3.7.2.2

A_m/A_s	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
e	1.5	1.23	1.16	1.11	1.09	1.07	1.06	1.05	1.05	1.04	1.04
c	0.0	0.44	0.62	0.71	0.76	0.80	0.83	0.85	0.87	0.88	0.89

A_m, A_s – cross-sectional area of flange and web plate, respectively, [cm^2].

10.3.7.3 Direct Calculations

10.3.7.3.1 For web frame configurations and boundary conditions other than those specified in sub-chapter 10.3.7.2, a direct stress calculation shall be performed.

Concentrated load on the web frame shall be determined in accordance with sub-chapter 10.3.7.1. The point of application is in each case to be chosen in relation to the arrangement of stringers and longitudinal frames so as to obtain the maximum shear forces and bending moments.

The allowable stresses are as follows:

– shear stress $\tau = \frac{R_e}{\sqrt{3}}$, [MPa] (10.3.7.3.1-1)

– bending stress $\sigma = R_e$, [MPa] (10.3.7.3.1-2)

– equivalent stress $\sigma_e = \sqrt{\sigma^2 + 3\tau^2} = R_e$, [MPa]. (10.3.7.3.1-3)

10.3.8 Bow

10.3.8.1 Stem

10.3.8.1.1 The stem shall be made of rolled, cast or forged steel or shaped steel plates. A sharp edged stem (see Fig. 10.3.8.1.1) improves the ship manoeuvrability in ice and is recommended particularly for smaller ships with a length under 150 m.

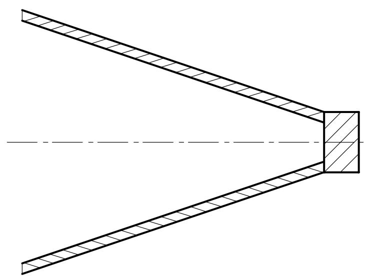


Fig. 10.3.8.1.1 Example of suitable stem

10.3.8.1.2 Plate thickness of a shaped plate stem and in the case of a blunt bow, any part of the shell which forms an angle of 30° or more to the centreline in a horizontal plane, shall be calculated in accordance with the requirements specified in paragraph 10.3.4.2 assuming that:

s – spacing of elements supporting the plate, [m];
p_1 = p, [MPa] (see sub-chapter 10.3.4.2);
l_a – spacing of vertical supporting elements, [m].

10.3.8.1.3 The stem and the part of a blunt bow defined in paragraph 10.3.8.1.2 shall be supported by floors or brackets spaced not more than 0.6 m apart and having a thickness of at least half the plate thickness.

Stem reinforcement shall extend from the keel to a point 0.75 m above *LWL* or, in case an upper forward ice belt is required (see sub-chapter 10.3.4.1) – to the upper limit of this region.

10.3.8.2 Arrangements for Towing

10.3.8.2.1 A mooring pipe with an opening not less than 250 by 300 mm, a length of at least 150 mm and an inner surface radius of at least 100 mm shall be fitted in the bow bulwark at the centre plane.

10.3.8.2.2 A bitt or other means for securing a towline, dimensioned to stand the breaking force of the towline of the ship, shall be fitted.

10.3.9 Stern

Introduction of new propulsion arrangements with azimuthing thrusters or "podded" propellers, which provide improved manoeuvrability, will result in an increased ice loading of the aft region. This fact shall be taken into account in the design of the aft/stern structure.

10.3.9.1 An extremely narrow clearance between the propeller blade tip and the stern frame shall be avoided as a small clearance would cause very high loads on the blade tip.

10.3.9.2 On twin and triple screw ships, the ice strengthening of the shell and framing shall be extended to the double bottom for 1.5 m forward and aft of the side propellers.

10.3.9.3 Shafting and stern tubes of side propellers shall normally be enclosed within plated bossings. If detached struts are used, their design, strength and attachment to the hull shall be duly considered.

10.3.9.4 A wide transom stern extending below the *LWL* will seriously impede the capability of the ship to back in ice, which is most essential. Therefore a transom stern shall not be extended below the *LWL*, if this can be avoided. If unavoidable, the part of the transom below the *LWL* shall be kept as narrow as possible. The part of a transom stern situated within the ice belt shall be strengthened as for the midship region.

10.3.10 Bilge Keels

10.3.10.1 Connection of bilge keels to the hull shall be so designed that the risk of damage to the hull, in case a bilge keel is ripped off, is minimized.

10.3.10.2 To limit damage when a bilge keel is partly ripped off, it is recommended that the bilge keels be cut up into several shorter independent lengths.

ANNEX Z1

CALCULATIONS OF BENDING MOMENT LIMIT VALUE

11 CHECKING OF THE HULL LIMIT STRENGTH

11.1 Preliminary Notes

11.1.1 The present Annex contains description of approximate method for determination of dependences between values of bending moment M in the hull cross-section and the curvature χ of the deflection line, as well as for calculations of the limit value M_{gr} of the moment M.

The method is incremental, and the calculations are of iterative character.

Method is described in paragraph 2.1.

11.1.2 Calculations method is applicable to the steel hull.

Determination of M_{gr} for structures made of other materials shall be considered separately.

12 Determining $M - \chi$ Dependence

12.1 Approximate Incremental-iterative Method for Calculation of $M–\chi$ Dependence

12.1.1 Description of the Method

Dependence $M - \chi$ is determined by incremental – iterative method presented schematically on Fig. 2.1.1.

In this method limit value of the moment M_{gr} in the hull cross-section is identified with the extreme value of the bending moment M on the graph of $M(\chi)$ dependence. The graph is determined by incrementally-iterative method.

In each iterative step the value of bending moment M_i in the cross-section is determined, which corresponds to the set value χ_i of curvature of the hull deflection line.

The χ_i value is assumed in a form:

$$\chi_i = \chi_{i-1} + \Delta\chi \text{, [1/m]} \qquad (2.1.1\text{-}1)$$

where:

χ_{i-1} – value of the curvature in the previous step of calculations;

$\Delta\chi$ – established increase in the curvature.

Increase in the curvature determines change of the value of the hull cross-section rotation around its horizontal neutral axis angle.

Change of the rotation angle causes deformation ε in the hull elements in the direction along the axis of the hull, with values depending on the location of the elements.

Values of normal stresses σ in particular elements, corresponding strains, are determined on the basis of dependence $\sigma - \varepsilon$ with non-linearity consideration, e.g. in elastic – plastic range of material strains.

Dependence $\sigma - \varepsilon$ is non-linear and, in connection with such stresses distribution σ in particular elements of the hull cross-section, forces change neutral axis position in each calculations step. New position of neutral axis in each calculations step is determined iteratively, using the equilibrium condition of stresses in cross-section of the hull.

After determination of neutral axis position and stresses σ distribution in the hull cross-section, bending moment M_i, corresponding to given value of curvature χ_i, is determined in relation to neutral axis by summation of M_i components from particular elements constituting cross-section.

Incremental – iterative procedure consists of following calculation stages (see also Fig. 2.1.1):

Stage 1 – division of the hull cross-section into stiffened panels;

Stage 2 – determination of dependence between stresses and strains ($\sigma - \varepsilon$) for particular panels (see Table 2.2.1);

Stage 3 – assumption of preliminary value of the curvature $\chi = \chi_0 = 0.01\varepsilon_\gamma$ (ε_γ – strains corresponding to $\sigma = R_e$) and determination of neutral axis position in the first step of calculations;

Stage 4 – calculation of strains $\varepsilon_i = \chi(z_i - z_0)$ (z_i – vertical co-ordinate of the element, z_0 – neutral axis co-ordinate) and stresses σ_i in particular elements of the hull cross-section;

Stage 5 – calculation of neutral axis co-ordinate z_0^* corresponding to assumed curvature χ, which ensures compliance with the condition:
$\sum A_i \sigma_i = \sum A_j \sigma_j$ ("i" elements – compressed, "j" elements – tensioned, A – element section area);

Stage 6 – calculation of bending moment M value corresponding to assumed curvature, by summation of portions from particular elements of cross-section:

$$M = \sum |\sigma_i| \; A_i \left| z_i - z_0^* \right|$$

Stage 7 – comparison of the moment M with the relevant value corresponding to the previous value of curvature.

If M increase is negative, and its absolute value is less than the preset measurement accuracy of calculations, the calculations process is completed; $M_{gr} = M$ is assumed.

Otherwise χ is increased by $\Delta\chi$ and the calculations shall return to the stage 4.

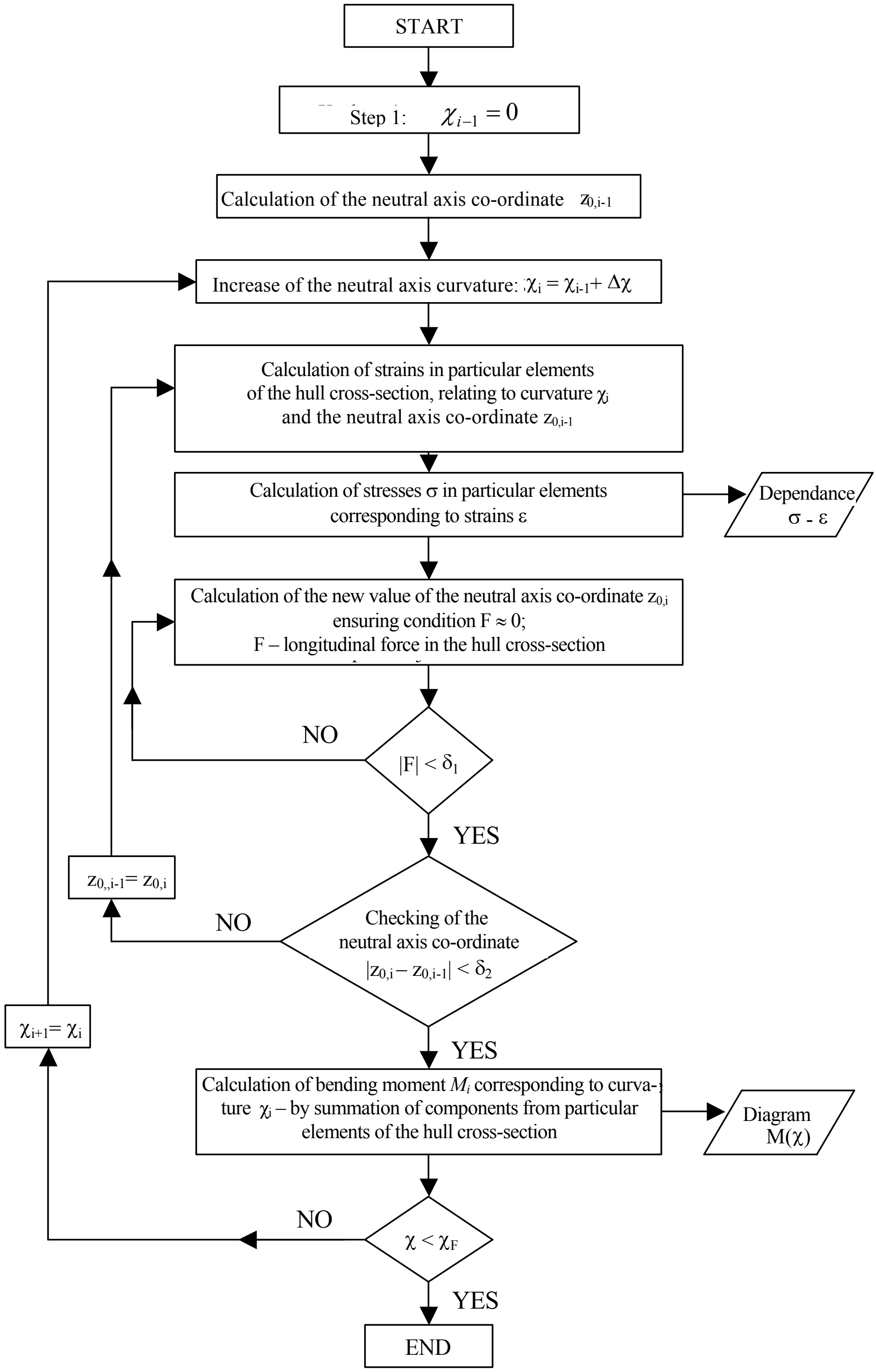


Fig. 2.1.1 Procedure for determination of $M(\chi)$ dependence

12.1.2 Assumptions for Incrementally-Iterative Method of Calculations

When applying calculations procedure acc. to 2.1.1, following assumption shall be made:

- Limit moment is determined in the hull cross-sections between neighbouring transverse girders (bottom, sides, beams).
- The hull cross-sections remain flat at any value of curvature χ.
- Material (steel) becomes strained in elastic-plastic range.
- The hull cross-section is divided into finite number of elements between which there is no feedback.

  The above elements are:
  - panels stiffened transversally or longitudinal stiffeners, with a plating strip, 2.2.1;
  - rigid elements of the hull (in. regions of plates' connection which do not lie in the same plane), the strength characteristics of which are formulated in 2.2.2.
- Bending moment M_i in the hull cross-section corresponding to curvature χ_i of the deflection line is calculated as an effect of stresses σ acting in particular elements. Stresses σ corresponding to strains ε directly dependent on the curvature (increased in the following steps) are determined on the basis of nonlinear dependencies $\sigma - \varepsilon$, determined for particular elements. These dependencies, determined for various forms of element destruction, are provided in 2.2. The smallest value σ resulting from considered dependencies $\sigma - \varepsilon$ is selected.
- The calculations are led until the value χ_F of the curvature, [1/m], determined from formula (for the hull hogging and sagging) is obtained;

$$\chi_F = \pm 0.003 \frac{M_y}{EI} \qquad (2.1.2\text{-}1)$$

where:

E – Young's modulus, [MPa], (for steel E = 206 000 MPa);

I – the hull cross-section moment of inertia, [m^4], determined according to requirements of B/15.7;

M_y – the lesser value of the two following:

$$M_{y1} = R_e \cdot W_d \qquad (2.1.2\text{-}2)$$

$$M_{y2} = R_e \cdot W_p \qquad (2.1.2\text{-}3)$$

R_e – yield point, [MPa]

W_d, W_p – the hull section moduli in relation to the bottom and strength deck, [m^3], determined in accordance with principles provided in B/15.7.

If in the interval $0 < \chi \le \chi_F$ the maximum of function M(χ) do not occur, calculations for $\chi > \chi_F$ shall be led – until the maximum value of M is found.

12.2 Dependencies $\sigma - \varepsilon$

12.2.1 Plating Panels and Stiffeners

Forms of capacity exhaustion of the stiffened panels and stiffeners provided in Table 2.2.1 shall be taken into account.

Table 2.2.1

Element of the structure	The form of load limit exhaustion	Dependencies $\sigma - \varepsilon$
Tensioned elements: – panels stiffened transversally; – longitudinal stiffeners or girders	Elastic-plastic strains	Acc. to 2.2.3
Compressed longitudinal stiffeners or girders	Flexural buckling Torsional buckling Local buckling of stiffener web /girders with face plate Flat bars buckling	Acc. to 2.2.4 Acc. to 2.2.5 Acc. to 2.2.6 Acc. to 2.2.7
Compressed panels transversally stiffened	Plates buckling	Acc. to 2.2.8

12.2.2 Capacity of Rigid Elements

Rigid elements of the hull (e.g. regions of plates' connection which do not lie in the same plane) exhaust their capacity, in general, in a form of plastic flow.

Relevant dependencies $\sigma - \varepsilon$ for tensioned or compressed elements shall be determined acc. to 2.2.3.

12.2.3 Elastic-plastic Strains of the Hull Structure Elements

Elastic-plastic strains in the hull cross-sections of tensioned elements are described by the following equations (see also Fig. 2.2.3)

$$\sigma = \phi \cdot R_e, \text{ [MPa]} \qquad (2.2.3\text{-}1)$$

where:

$$\phi = -1 \text{ for } \varepsilon < -1 \qquad (2.2.3\text{-}2)$$

$$\phi = \varepsilon \text{ for } -1 \le \varepsilon \le 1 \qquad (2.2.3\text{-}3)$$

$$\phi = 1 \text{ for } \varepsilon \ge 1 \qquad (2.2.3\text{-}4)$$

$$\varepsilon = \frac{\varepsilon_E}{\varepsilon_y} \qquad (2.2.3\text{-}5)$$

ε_E – normal strains of the element (along hull axis)

$$\varepsilon_y = \frac{R_e}{E} \qquad (2.2.3\text{-}6)$$

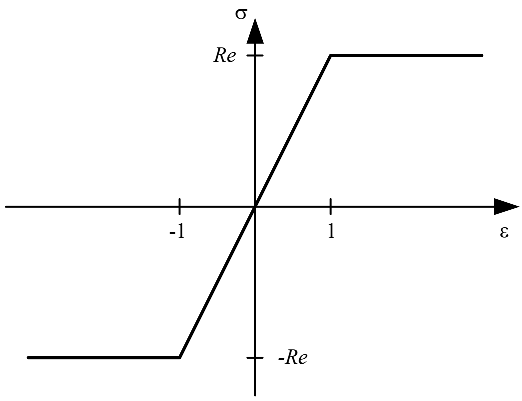


Fig. 2.2.3 Dependence $\sigma - \varepsilon$ for elastic-plastic strains

12.2.4 Flexural Buckling

Elastic-plastic strains $\sigma_{cr1} - \varepsilon$ of compressed stiffeners, corresponding to buckling in a flexural form, shall be determined from the formula (see also Fig. 2.2.4):

$$\sigma_{cr1} = \phi\,\sigma_{c1}\,\frac{A_s + 10\,b_E t_p}{A_s + 10\,s\,t_p} \qquad (2.2.4\text{-}1)$$

where:

ϕ – function defined in 2.2.3;

σ_{c1} – critical stresses, [MPa]:

$$\sigma_{c1} = \frac{\sigma_{E1}}{\varepsilon} \text{ dla } \sigma_{E1} \le \frac{1}{2} R_e \varepsilon \qquad (2.2.4\text{-}2)$$

$$\sigma_{c1} = R_e\left(1 - \frac{\phi R_E \varepsilon}{4\sigma_{E1}}\right) \text{ for } \sigma_{E1} > \frac{1}{2} R_e \varepsilon \qquad (2.2.4\text{-}3)$$

ε – defined in 2.2.3;

σ_{E1} – theoretical critical stresses, [MPa]:

$$\sigma_{E1} = \pi^2 E \frac{I_E}{A_E l^2} 10^4 \qquad (2.2.4\text{-}4)$$

I_E – stiffener transfer section moment of inertia, [cm^4], together with the plating effective flange with width b_{E1} (for net thickness);

b_{E1} – width of the plating effective flange, [m]:

$$b_{E1} = \frac{s}{\beta_E} \quad \text{for } \beta_E > 1.0 \qquad (2.2.4\text{-}5)$$

$$b_{E1} = s \quad \text{for } \beta_E \le 1.0 \tag{2.2.4-6}$$

$$\beta_E = 10^3 \frac{s}{t_p}\sqrt{\frac{\varepsilon \cdot R_e}{E}} \tag{2.2.4-7}$$

s – stiffeners' spacing, [m];

t_p – plating thickness (net), [mm];

A_E – cross-section area of the stiffener with plating effective flange with width b_E ,[cm^2] (for net thickness);

b_E – value of effective width of plating strake:

$$b_E = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E{}^2}\right)s \quad \text{for } \beta_E > 1.25 \tag{2.2.4-8}$$

$$b_E = s \quad \text{for } \beta_E \le 1.25 \tag{2.2.4-9}$$

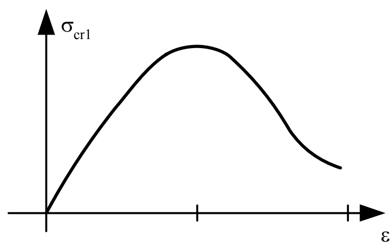


Fig. 2.2.4 Dependence $\sigma_{cr1} - \varepsilon$ (pictorial)

12.2.5 Flexural Buckling

Elastic-plastic strains $\sigma_{cr2} - \varepsilon$ of compressed stiffeners, corresponding to buckling in a torsional form, shall be determined from the formula (see also Fig. 2.2.5):

$$\sigma_{cr2} = \phi \frac{A_s \sigma_{c2} + 10 s t_p \sigma_{cp}}{A_s + 10 s t_p}, \ [\text{MPa}] \tag{2.2.5-1}$$

where:

ϕ – function defined in 2.2.3

σ_{c2} – critical stresses:

$$\sigma_{c2} = \frac{\sigma_{E2}}{\varepsilon} \quad \text{for } \sigma_{E2} \le \frac{1}{2} R_e \varepsilon \tag{2.2.5-2}$$

$$\sigma_{c2} = R_e \left(1 + \frac{\phi R_e \varepsilon}{4\sigma_{E2}}\right) \quad \text{for } \sigma_{E2} > \frac{1}{2} R_e \varepsilon \tag{2.2.5-3}$$

σ_{E2} – theoretical critical stresses, [MPa], calculated acc. to B/13.5.3.3;

ε – defined in 2.2.3;

A_s – stiffener transverse section area (net), [cm^2];

s, t_p – defined in 2.2.4;

σ_{cp} – critical stresses of compressed plating, [MPa]:

$$\sigma_{cp} = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E{}^2} \right) \text{ for } \beta_E > 1.25 \qquad (2.2.5\text{-}4)$$

$$\sigma_{cp} = R_e \text{ for } \beta_E \le 1.25$$

β_E – factor defined in 2.2.4.

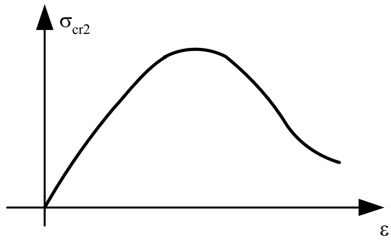


Fig. 2.2.5 Dependence $\sigma_{cr2} - \varepsilon$ (pictorial)

12.2.6 Buckling of Stiffeners or Girder Webs with Face Plates

Elastic-plastic strains $\sigma_{cr3} - \varepsilon$ compressed webs of stiffeners or girders with face plates, associated with local web buckling, shall be determined from the formula:

$$\sigma_{cr3} = \phi R_e \frac{10^3 b_E t_p + h_{WE} t_w + b_m t_m}{10^3 s t_p + h_w \cdot t_w + b_m \cdot t_m}, \text{ [MPa]} \qquad (2.2.6\text{-}1)$$

where:

ϕ – defined in 2.2.3;

b_E, s, t_p – defined in 2.2.4;

h_w – web height, [mm];

t_w – web net thickness, [mm];

b_m – face plate width, [mm];

t_m – face plate net thickness, [mm];

h_{WE} – effective web height, [mm]:

$$h_{WE} = \left(\frac{2.25}{\beta_w} - \frac{1.25}{\beta_w{}^2} \right) h_w \quad \text{for } \beta_w > 1.25 \tag{2.2.6-2}$$

$$h_{WE} = h_w \quad \text{for } \beta_w \le 1.25 \tag{2.2.6-3}$$

$$\beta_w = \frac{h_w}{t_w} \sqrt{\frac{\varepsilon R_e}{E}}$$

ε – defined in 2.2.3.

12.2.7 Local Buckling of Flat Bar Stiffeners

Elastic-plastic strains $\sigma_{cr4} - \varepsilon$ corresponding to local buckling of stiffeners in a form of flat bar, shall be determined from the formula (see also Fig. 2.2.7):

$$\sigma_{cr4} = \phi \frac{10st_p \cdot \sigma_{cp} + A_s \cdot \sigma_{c4}}{A_s + 10st_p}, \text{ [MPa]} \tag{2.2.7-1}$$

where:

ϕ – defined in 2.2.3;

s, t_p – defined in 2.2.4;

A_s – stiffener transfer section area (net), [cm^2];

σ_{cp} – acc. to 2.2.5;

σ_{c4} – critical stresses:

$$\sigma_{c4} = \frac{\sigma_{E4}}{\varepsilon} \quad \text{for } \sigma_{E4} \le \frac{1}{2} R_e \varepsilon \tag{2.2.7-2}$$

$$\sigma_{c4} = R_e \left(1 - \frac{\phi R_e \varepsilon}{4\sigma_{E4}} \right) \quad \text{for } \sigma_{E4} > \frac{1}{2} R_e \varepsilon \tag{2.2.7-3}$$

σ_{E4} – theoretical critical stresses, [MPa]:

$$\sigma_{E4} = 160000 \left(\frac{t_w}{h_w} \right)^2 \tag{2.2.7-4}$$

ε – defined in 2.2.3.

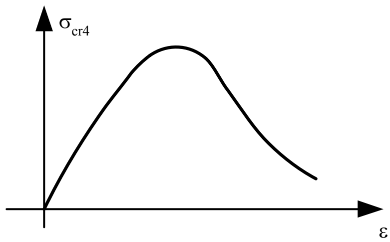


Fig. 2.2.7 Dependence $\sigma_{cr4} - \varepsilon$ (pictorial)

12.2.8 Buckling of the Plating Transversally Stiffened

Elastic-plastic strains $\sigma_{cr5} - \varepsilon$ corresponding to plates' buckling of transversally stiffened plating shall be determined from the formula:

$$\sigma_{cr5} = R_e \left[\frac{s}{l} \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E{}^2} \right) + 0.1 \left(1 - \frac{s}{l} \right) \left(1 + \frac{1}{\beta_E{}^2} \right) \right], \text{ [MPa]} \qquad (2.2.8)$$

where:

s – stiffeners spacing, [m];

l – length of the plate side in transverse direction (e.g. equal to spacing of the longitudinal girders), [m];

β_E – defined in 2.2.4.