Polski Rejestr Statków

RULES

PUBLICATION NO. 118/P

REQUIREMENTS FOR PASSENGER SHIPS CONSTRUCTED OF POLYMER COMPOSITES, ENGAGED ON DOMESTIC VOYAGES

2018

Publications P (Additional Rule Requirements) issued by Polski Rejestr Statków
complete or extend the Rules and are mandatory where applicable

GDAŃSK

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PRS/OP, 12/2017

CONTENTS

1 APPLICATION

1.1 The rules of this Publication *Publication Requirements for passenger ships constructed of polymer composites, engaged on domestic voyages* apply to passenger ships having hulls and/or superstructures made of polymer composites and of length up to 50 m, engaged in domestic navigation. For ships approved for the carriage of 100 and more passengers, the structure and fire protection arrangements are subject to additional assessment within engineering analysis (see 3.3).

For ships of length L < 24 m made of grp laminates, requirements of the *Rules for the Classification and Construction of Small Sea-going Ships, Part II – Hull* may be applied.

1.2 The requirements of these *Rules* are related to: dimensioning structures – both monolithic and sandwich, polymer materials, construction technology, fire protection and escape routes.

1.3 Additional conditions for safe navigation, including the number, kind and arrangement of life-saving equipment and means are defined in the separate regulations of Administration.

2 GENERAL DEFINITIONS AND TERMS

2.1 Definitions and detailed terms can be found in chapters where the definitions and terms are applicable.

2.2 General definitions and terms

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

D – displacement of ship, [t] – mass of water, in tonnes, of the volume equal to the volume of the submerged part of the ship's hull. Unless otherwise specified, the seawater mass density shall be taken as 1.025 t/m^3.

H – moulded depth of ship, [m] – vertical distance measured amidships from the base plane to the top of the uppermost continuous deck beam at side. In ships having a rounded gunwale, the moulded depth shall be measured to the point of intersection of the moulded lines of the deck and side.
If the uppermost continuous deck is stepped and the raised part of the deck extends over the point at which the moulded depth shall be determined, the moulded depth shall be measured to a line of reference extending from the lower part of the deck along a line parallel with the raised part.

L – length of ship – means 96% of the total length of hull measured on the waterline at 85% of the least moulded depth measured from the top of the keel, or the length from the fore side of the stem to the axis of the rudder stock on that waterline, whichever is greater.
In ships designed with a rake of keel, the waterline on which this length is measured shall be parallel to the design waterline.
For ships of unconventional stem or stern curvature, the length L shall be determined in agreement with PRS.

L_0 – design length of ship, [m] – distance measured on the summer load waterline from the fore side of the stem to the axis of the rudder stock. The adopted value of L_0, shall not be taken less than 96% of the overall length of hull measured on the summer load waterline, however not more than 97% of that length. For ships with unconventional stem or stern curvature, length L_0 shall be determined in agreement with PRS.

T – moulded draught, [m] – vertical distance measured amidships from the base plane to the summer load waterline.

Deck erection – superstructure or deckhouse.

Superstructure – a decked structure on the freeboard deck, extending from side to side of the ship or with one side or both sides being inboard of the ship sides not more than 0.04*B*.

Deckhouse – a decked structure on the freeboard deck or on the superstructure deck with the sides being inboard of one or both ship sides more than 0.04 *B*.

U p p e r   d e c k – the uppermost continuous deck extending over the full length of the ship.

B u l k h e a d   d e c k – the uppermost deck up to which main transverse watertight bulkheads are extended.

S u p e r s t r u c t u r e   d e c k – 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.

F r e e b o a r d   d e c k – deck to which the freeboard is measured and calculated in accordance with the *International Convention on Load Lines, 1966*.

3 GENERAL REQUIREMENTS

3.1 The ship shall be so designed and escape means so arranged that passengers can be evacuated in controlled conditions, within not more than one third of the time of structural fire protection, defined in 10.1.6.3.7, for high fire risk areas, reduced by 7 minutes assigned for initial detection and extinguishing.

$$\mathit{Evacuation\ time} = \frac{(SFP - 7)}{3} \quad \text{[min]} \tag{3.1}$$

where:
SFP – time of structural fire protection, [min].

The document *Analysis of passenger evacuation time in emergency* is subject to PRS assessment.

Additionally, the time of passengers evacuation shall be practically verified during harbor trials, in accordance with the *International High Speed Craft Safety Code*, paragraphs 4.8.3 to 4.8.11.

3.2 Ships complying with requirements of these Rules (in their scope) and of the *PRS Rules for the Classification and Construction of Sea-going Ships* or the *PRS Rules for the Classification and Construction of Small Sea-going Ships* within the scope of hull equipment, stability and subdivision, machinery equipment, engines, mechanisms, electrical systems, control systems and materials and welding, are assigned mark FRP PASSENGER SHIP or FRPpas, respectively, in the symbol of class.

3.3 Engineering analysis

3.3.1 The engineering analysis is aimed at proving that structures and fire safety arrangements adopted to a FRP ship comply with required fire safety criteria contained in *Directive 2009/45/EC*.

The above engineering analysis shall be performed for passenger ships carrying 100 or more passengers within the scope given in *SOLAS, II-2,* Regulation 17. The analysis is subject to PRS assessment and then Administration approval.

4 TECHNICAL DOCUMENTATION

4.1 The scope of required documentation is given in particular chapters of these *Rules* and below in 4.2

4.2 The PRS H.O. assessment shall cover:
1. *Analysis of passenger evacuation time in emergency*;
2. The engineering analysis and the analysis of arrangements for fulfilling fire safety criteria contained in *Directive 2009/45/EC*, acc. to requirements of *SOLAS II-2, Regulation 17* – for ships carrying 100 and more passengers.

5 APPROVAL PRINCIPLES FOR MATERIALS, MANUFACTURERS, TECHNOLOGY AGREEMENTS

5.1 Scope of supervision

5.1.1 Provisions determining the scope and course of supervision are given in the PRS issued *Supervision Activity Regulations*.

5.1.1.1 PRS supervision of the manufacture of materials and products covers:

.1 consideration of technical documentation,
.2 approval of the materials and products manufacturers,
.3 approval of the product type,
.4 testing materials and products,
.5 issue of relevant PRS documents, after completed supervision.

5.2 Approval of the materials and products manufacturers

5.2.1 The manufacturer seeking approval shall submit to PRS a written application/request, including:

- characteristics of the material,
- designation of the material,
- description of the manufacturing procedure and information on the quality management system,
- proposed scope of approval,
- proposed acceptance test programme.

The application/request shall also provide information on previous experience of the manufacturer in the production of materials subject to approval.

5.2.2 After consideration of the data provided in the application/request, PRS agrees, with the manufacturer, the programme of the material approval tests and carries out the inspection of the manufacturer.

The approval tests shall be carried out under the survey of PRS.

The approval granted to the manufacturer must not be transferred to other manufacturers and PRS shall be notified of any alterations introduced to the material manufacturing procedure.

5.2.3 The approval procedure mentioned above also applies to the already approved manufacturers wishing to extend the existing scope of approval or to manufacturers introducing new manufacturing technologies.

5.3 Approval of materials and products (indirect supervision)

5.3.1 PRS may approve the series production of certain types of materials and products, whose workmanship complies with the quality requirements specified for the products used in shipbuilding, and may issue relevant *Type Approval Certificate.*

5.3.2 The manufacturer seeking approval for its products shall submit to PRS a written application/request, including:

- characteristics of the product,
- designation of the product,
- description of the manufacturing procedure and information on the quality management system,
- proposed scope of approval,
- proposed acceptance tests programme.

5.3.3 After consideration of the data provided in the application/request, PRS agrees, with the manufacturer, the programme of the product acceptance tests and carries out the inspection of the manufacturer.

The approval tests shall be carried out under the survey of PRS.

The approval granted to the manufacturer must not be transferred to other manufacturers and PRS shall be notified of any alterations introduced to the manufacturing procedure.

5.3.4 The approval procedure mentioned above also applies to the already approved manufacturers wishing to extend the existing scope of approval.

5.3.5 Performance of approval tests

5.3.5.1 The approval tests shall be performed at PRS approved laboratories or under PRS surveyor supervision.

5.3.5.2 If the tests results are unsatisfactory, re-tests may be performed, subject to the following:

.1 if the unsatisfactory results are due to the local defects in the specimen material, the tests shall be repeated on the same number of specimens;

.2 if the unsatisfactory results are due to the inappropriate quality of the material, the tests shall be repeated on a double number of the specimens taken from the same material. If satisfactory results are obtained from the repeated test, the material from which additional specimens were cut, as well as the remaining materials belonging to the same batch, may be accepted. If, during a repeated test, at least one of the specimens proves unsatisfactory, the material shall be rejected.

5.3.5.3 PRS reserves the right to repeat the tests if confusion of specimens or test results occurred or the test results do not allow to assess the material quality with the required accuracy.

5.3.5.4 If the properties of the material only slightly differ from those required by this *Publication*, such material may be approved for further use, at the manufacturer's request, only upon special consideration by PRS Head Office.

5.4 Marking

5.4.1 Materials shall be marked in accordance with the relevant standards.

5.4.2 If the products are supplied in single pieces, each of them shall be marked.

5.4.3 In the case of supplying small-size products, their marking shall be agreed with PRS.

5.4.4 In each case, the marks on the products shall contain at least the following particulars:

.1 grade or type of the material,

.2 number of batch or other marking allowing to ascertain that the product belongs to the batch for which the appropriate certificate has been issued,

.3 manufacturer's name or brand,

.4 stamp of manufacturer's control,

.5 PRS acceptance mark or oval stamp.

6 MATERIALS USED FOR THE MANUFACTURE OF LAMINATES; PROPERTIES OF LAMINATES AND SANDWICH STRUCTURES

6.1 Definitions

Polymer composites – materials composed of at least two components (with visible boundaries between each other) having properties superior to these of a single component, e.g. glass-reinforced polymers.

Laminate – a composite of layer reinforcement, with resin (binder) being the only bonding agent for individual layers.

Reinforcement – a composite component, basic load-carrying element.

Binder – the resin bonding reinforcement fibres together, carrying loads between laminate fibres and layers.

Glass fibres – fibres made from various types of low-alkaline melted glass (diameter 6 – 15 μm).

Carbon fibres – fibres of at least 80 – 90% content of graphite. They are made by carbonization of other fibres (e.g. of polyacrylonitryle) or by other methods.

Standard HT/HS carbon fibres (HT – high tenacity/HS – high strength) – they characterize by R_m ~ 3500 – 5000 MPa, E ~ 235 GPa.

Intermediate modulus (IM) carbon fibres – carbon fibres of intermediate modulus between standard and high modulus fibres, having the highest strength among carbon fibres (modulus E ~ 295 GPa).

High modulus (HM) carbon fibres – fibres of high modulus (E > 370 GPa), having higher modulus E and lower strength and lower destructive elongation than standard fibres.

A r a m i d f i b r e s – fibres made of lyotropic liquid-crystal polymers from the aromatic polyamides group.

P o l y e s t e r r e s i n s (u n s a t u r a t e d p o l y e s t e r r e s i n s) – linear condensation polymers received by esterification of 2-carboxylic acids or their anhydrides and dihydric alcohols.

V i n y l e s t e r r e s i n s – are the result of reacting epoxy resins with 1-carbocylic unsaturated acids. They are of better quality than polyester resins and have almost the same technological properties.

E p o x y r e s i n s – are the result of condensation of e.g. epichlorohydrin or diane and epichlorohydrin. Epoxy resins quality is in general better than that of polyester and vinyl ester resins. Their physical properties, including strength properties, depend to a large extent on applied hardeners.

R e i n f o r c e m e n t s u r f a c e d e n s i t y – surface mass (g/m^2) of the reinforcement in the form of mats, fabrics.

F i b r e g l a s s m a t – fibres bonded of fibreglass roving strips (made only of E-glass) cut into short sections (30 – 50 mm) with accidental stripes direction, thus creating material of isotropic plane.

F a b r i c – the loom-woven reinforcement of plain, diagonal or satin weave.

B i a x i a l – biaxial reinforcement (0/90° or ± 45°) made by sewing together two unidirectional layers, with fibres laid transversely against each other.

M u l t i a x i a l – sewn reinforcements made of many unidirectional layers, with fibres laid at different angles against each other.

U n i d i r e c t i o n a l f a b r i c – the fabric woven of reinforcement stripes having large and small cross-section of fibres, so that the cross-section per unit of width normally differs by a dozen times along the warp and weft.

R o v i n g – a split of normally 6 to 60 stripes of fibreglass, where a strip means 50-400 glass fibres received at once using one machine.

6.2 Tests of laminate properties

6.2.1 General

Unless otherwise specified in other chapters of this Publication, all plastics and organic origin materials shall comply with the following requirements:

.1 they shall neither be flammable nor produce excessive amounts of smoke nor bring a hazard of poisoning, nor a hazard of explosion at elevated temperatures;

.2 unless other service temperature limits need to be specified due to service conditions, the materials shall ensure reliable operation of structures and products in the following temperature ranges:
- on weather deck: –40°C to +70°C,
- in the ship internal compartments: –10°C to +70°C;

.3 during the service, they shall neither release any harmful substances, nor become brittle, and their mechanical properties shall not reduce by more than 30% of the initial state;

.4 they shall be rot-proof and mould-proof and shall have no adverse effect on other materials being in contact with them.

6.2.2 Test conditions

6.2.2.1 Prior to tests, specimens shall be conditioned at a temperature 23 ±2°C and relative humidity 50 ±5% for at least 16 h.

The testing shall be performed immediately after the conditioning.

6.2.2.2 Test specimens of fabric-reinforced plastics shall be cut with their axes parallel with the reinforcement weft or warp.

The specimens for testing of anisotropic materials shall have their main axes parallel with or perpendicular to the expected anisotropy directions.

6.2.2.3 In justified cases, subject to agreement with PRS, the tests may be performed on specimens with shapes or dimensions different from those required by this Chapter.

6.2.2.4 The tests shall be performed, upon agreement with PRS, in accordance with relevant standards. Test conditions and used methods not addressed in this chapter shall be agreed with PRS.

6.2.2.5 Tensile strength test

6.2.2.5.1 The tensile strength of non-reinforced plastics shall be determined using a testing machine ensuring both maintaining of the required gripping jaw travelling speed and measurement of the specimen tensile stress. The extensometer shall enable measurement of tensile strain of the specimen gauge length with the accuracy of at least 1%. When determining the tensile strength, it is necessary to record the strain increase as a function of the specimen load. Modulus of elasticity in tension shall also be determined.

The testing shall be performed at a temperature of 23 ± 2 °C and a relative humidity of 50 ± 5% on 5 conditioned specimens, in accordance with ISO Standards 527-1[1)] and 527-2[2)].

The measurement shall be carried out with a gauge speed specified in relevant standards concerning the tested material and corresponding to one of the speeds given in Table 6.2.2.5.1.

Table 6.2.2.5.1

Speed [mm/min]
1 ± 0.5
5 ± 1.0
50 ± 5.0
100 ± 10.0
500 ± 50.0

Tensile strength of reinforced plastics shall be tested by determining the stress at break and the modulus of elasticity in tension. The testing shall be performed at a temperature of 23 ± 2 °C and a relative humidity of 50 ± 5% on 5 conditioned specimens, in accordance with ISO Standards 527-4[3)] and 527-5[4)].

6.2.2.6 Compressive strength test

6.2.2.6.1 Determining the compressive strength of plastics consists in loading the tested specimen with an increasing compressive load at specified testing speed, and measuring resulting specimen compressive strain.

The test shall be carried out on 5 conditioned specimens in the form of rectangular prism of dimensions specified in relevant standards. In case of anisotropic materials, at least 5 test specimens for each axis of anisotropy, shall be prepared.

The test shall be performed at the temperature of 23 ±2 °C and air relative humidity 50 ±5%, in accordance with ISO 604 Standard[5)].

The test speed shall not exceed 1.5 mm/min.

6.2.2.6.2 Compressive strength of rigid cellular plastics shall be determined by applying a compressive force to the specimen in the form of rectangular prism.

The test shall be carried out on 5 conditioned specimens in accordance with ISO Standard 844[6)].

The test shall continue, if possible until a relative displacement of at least 10% is reached. If the value of maximum compressive stress corresponds to a relative displacement of less than 10%, it shall be noted as the "compressive strength". However, if the value of the maximum compressive stress corresponds to

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1) ISO Standard 527-1:2012 Plastics – Determination of tensile properties – Part 1: General principles.
2) ISO Standard 527-2:2012 Plastics – Determination of tensile properties – Part 2: Test conditions for moulding and extrusion plastics.
3) ISO Standard 527-4:1997 Plastics – Determination of tensile properties – Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites.
4) ISO Standard 527-5:2009 Plastics – Determination of tensile properties – Part 5: Test conditions for unidirectional fibre-reinforced plastic composites.
5) ISO Standard 604:2002 Plastics – Determination of compressive properties.
6) ISO Standard 844:2014 Rigid cellular plastics – Determination of compression properties.

a relative displacement of more than 10%, this value shall be noted as the ”compressive stress at 10% relative displacement”.

6.2.2.7 Flexural strength test

6.2.2.7.1 Determination of flexural strength of reinforced plastics consists in applying of a momentary static flexural load to a specimen in the form of beam of rectangular cross-section, supported freely at two points on the testing machine, until the conventional deflection is achieved or the specimen is broken.

The test shall be carried out at a temperature of 23 ± 2 °C and a relative humidity of 50 ± 5%, on 5 conditioned specimens, in accordance with ISO Standard 14125[1)]. The edge radius of the supports shall be 2 ± 0.2 mm where the specimen thickness is equal or less than 3 mm, or 5 ± 0.2 mm where the specimen thickness is more than 3 mm. In the case of applying one loading member of edge radius equal to 5 ± 0.2 mm, the load shall be applied at the mid-span of the specimen. However, if two loading members of the edge radius equal to 2 ± 0.2 mm (for specimens equal or less than 3 mm in thickness) or 5 ± 0.2 mm (for specimens of more than 3 mm in thickness) are used, the load shall be applied in two points whose spacing is one third of the specimen's span between the testing machine supports.

6.2.2.7.2 For determining the flexural strength of rigid cellular plastics, a force shall be applied acting continuously at mid-span of the test specimen two supports spaced 300 mm apart.

The flexural load and deflection shall be recorded during the test.

The flexural test shall be carried out on 5 conditioned specimens according to ISO Standard 1209-2[2)]. If the test specimens rupture before the deflection reaches 5%, breaking load and strain shall be recorded and the test shall be finished.

6.2.2.8 Shear strength test

Determination of shear strength of cellular plastics consists in applying shearing stress to a specimen in the form of a rectangular prism using metal bars stuck to the specimen.

The shearing test shall be carried out at a temperature of 23 ± 2 °C on 5 conditioned specimens in accordance with ISO Standard 1922[3)], by pulling a movable grip off the fixed one with the speed of 1 ± 0.5 mm per minute and deflection not exceeding 10%. The force – displacement relation shall be recorded during the test.

An adhesive used to fasten the test specimen to metal bars shall be such as to ensure that the shear strength and the modulus of elasticity of adhesive joint be far greater than those of the tested cellular plastic. During testing, the cellular plastic shall be damaged, not the adhesive joint. The adhesive shall not affect the structure of the tested cellular material.

6.2.2.9 Impact test

Determination of impact strength consists in breaking the test specimen in the form of a horizontal beam supported at both ends, by a single pendulum machine hit in the centre of specimen between supports, and in the case of notched specimens – directly opposite the single notch. The striking edge shall hit the centre, perpendicularly to the specimen longitudinal axis with a tolerance of ± 2°. The impact energy shall be within the range 0.5 ∣50 J.

The impact test shall be carried out on 10 conditioned specimens in accordance with ISO Standard 179-1[4)]. In the case of notched specimens, the shape and dimensions of the notch shall be determined in accordance with the relevant standards. For specimens cut from sheets or plates which have anisotropic characteristics of impact properties, two groups of test specimens shall be cut with their major axes respectively parallel with and perpendicular to the reinforcement direction.

6.2.2.10 Determination of water absorption

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1) ISO Standard 14125:1998 Fibre-reinforced plastic composites – Determination of flexural properties.

2) ISO Standard 1209-2:2007 Rigid cellular plastics – Determination of flexural properties – Part 2: Determination of flexural strength and apparent flexural modulus of elasticity.

3) ISO Standard 1922:2012 Rigid cellular plastics – Determination of shear strength.

4) ISO Standard 179-1:2010 Plastics – Determination of Charpy impact properties – Part 1: Non-instrumented impact test.

6.2.2.10.1 Determination of water absorption by plastics consists in determining the change of mass of the specimen immersed in cold or boiling water for a strictly specified time and at a constant temperature. The test shall be performed on 3 specimens dried in the vacuum drying oven at a temperature of 50 ± 2 °C within 24 ± 1 hours and cooled in a desiccator at a temperature of 23 ± 2 °C. The test shall be performed in accordance with ISO Standard 62[1).]

Test specimens cut from thermoplastic, thermosetting and other moulding compounds shall be disc-shaped with a diameter of 50 ± 1 mm and thickness of 3 ± 0.2 mm. Specimens cut from sheets or plates shall be square with a side of 50 ±1 mm and thickness equal to the sheet thickness, however not more than 25 mm. Specimens from sections, bars and pipes shall be prepared as segments of 50 ± 1 mm in length. Sections' thickness shall be below 3 ± 0.2 mm whereas bar and pipe diameter and wall thickness shall be below 50 mm.

Water absorption is defined as a mass of water absorbed by the specimen either as the mass of water absorbed by the specimen surface unit, or as percentage ratio of the absorbed water mass to the specimen initial mass.

6.2.2.10.2 Determination of water absorption for rigid cellular plastics consists in measuring of the change of the buoyancy force of a specimen immersed 50 mm deep in an treated water (deaerated, distilled water, used at least 48 hours after distillation) for 96 ± 1 h.

The test shall be carried out at the temperature of 23 ± 2 °C and the relative humidity of 50 ±5% on 3 conditioned specimens of 150 ± 1 mm in length, 150 ± 1 mm in width, not exceeding 75 mm in thickness, and of a volume at least 500 cm^3, in accordance with ISO Standard 2896[2)]. For materials manufactured and used with natural or laminated skin, the specimen thickness shall be such as that of the product.

The water absorption means the percentage proportion of absorbed water volume to initial specimen volume. Swelling and open pores on the specimen surface shall be taken into account.

6.2.2.11 Ageing test

6.2.2.11.1 Determination of seawater resistance shall be carried out on the specimens whose number and sizes are subject to specification depending on the scope of testing. The specimens shall be immersed in the seawater of a temperature of 23 ± 2 °C for 28 days. After this period, the specimens shall be subjected to the agreed tests.

6.2.2.11.2 Determination of oil resistance shall be carried out on the specimens whose number and sizes are subject to specification depending on the scope of testing. The specimens shall be immersed in diesel oil of a temperature of 23 ± 2 °C for 28 days. After this period, the specimens shall be subjected to the agreed tests.

6.2.2.12 Dimensional stability test

The dimensional stability test of rigid cellular plastics consists in determining the changes of linear dimensions of conditioned specimens exposed to specified conditions within specified time and subjected to conditioning again after the exposure.

The test shall be performed on 3 specimens of the following dimensions:
length 100 ±1 mm,
width 100 ±1 mm,
thickness 25 ±0.5 mm
in accordance with ISO Standard 2796[3)].

The test shall be completed after 48 ± 2 h and the percentage change in the length, width and thickness shall be determined.

6.2.2.13 Determination of density

Apparent density of cellular plastics is determined by weighing the specimen, determining its volume by measurement of its dimensions at a temperature of 23 ± 2 °C and at a relative humidity of 50 ± 5%, and calculating the density as a quotient of the specimen mass and volume.

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1) ISO Standard 62:2008 Plastics – Determination of water absorption.
2) ISO Standard 2896:2001 Rigid cellular plastics – Determination of water absorption.
3) ISO Standard 2796:1986 Cellular plastics, rigid – Test for dimensional stability.

The density shall be determined on 5 conditioned specimens of a such shape that their volumes can be easily calculated and of the total surface area at least 100 cm^2, in accordance with ISO Standard 845[1)].

6.2.2.14 Determination of textile-glass content

The test shall be carried out on 4 specimens of laminate of a mass at least 2 g and a thickness not exceeding 5 mm. Calcinated crucible containing the specimen shall be subjected to calcination in a muffle furnace at a temperature of 625 ± 20 °C and heat to constant mass, in accordance with ISO Standard 1172[2)].

6.3 Polymer composites

6.3.1 Reinforced laminates

The requirements apply to glass-reinforced laminates used in ship structures and in the manufacture of products being subject to PRS survey.

Laminates shall be manufactured by a method approved, within the scope of the manufacturer's approval, by PRS and the conditions of their manufacturing and curing (temperature, humidity, time-period) shall comply with the conditions specified in the *Approval Certificate*.

6.3.1.1 Unsaturated polyester resins, vinyl resins and epoxy resins complying with the requirements of Chapter 6.5, shall be the bonding agent at the manufacture of laminates.

The resin manufacturer is required to provide specification on the supplied resin physical and chemical properties for the liquid condition and post-hardening condition, as well as the application instruction.

Neither pigments nor other dyeing agents, which could adversely affect the resin or laminate properties, shall be added; the addition of pigments is permitted only for resins used as protective or decorative layers (gelcoat resins).

6.3.1.2 The non-alkaline glass fibres, carbon and aramid fibres in the form of mats, fabrics, as well as continuous or chopped roving, complying with the requirements of Chapter 6.4, shall be used as the reinforcement.

The manufacturer of the reinforcing material shall provide the certificate for each batch of a material containing the following particulars:

.1 manufacturer's name,
.2 product name and marking,
.3 alkali metals oxides content (converted into Na_2O) – glass fibres,
.4 glass fibre diameter,
.5 fabric type (kind) and information on applied roving in warp and weft,
.6 tensile strength (for fabrics – parallel with warp and weft),
.7 kind of active preparation,
.8 kind of bonding agent (for chopped strand mats).

6.3.1.3 Laminate mechanical properties, such as tensile and compressive strength, shall be assumed depending on the reinforcement quantity and location, as well as on test conditions described in 6.3.3 and the data of chapter 9.4.2.10; the properties shall be agreed with PRS.

Influence of oils, seawater and other ageing agents shall not reduce the laminate mechanical properties by more than 30 percent, as compared with the initial values.

6.3.1.4 For laminates used in structures or products exposed to loads, a minimum content of glass fibre shall be 25 percent, while in the case of chopped strand mat reinforced plastics the glass fibre content shall not exceed 35%.

6.3.2 Verification of design parameters of reinforcement used in hull structure

[1)] Norma ISO 845:2006 Cellular plastics and rubbers – Determination of apparent (bulk) density.
[2)] ISO Standard 1172:1996 Textile glass reinforced plastics – Prepregs, moulding compounds and laminates – Determination of the textile-glass and mineral-filler content – Calcination methods.

6.3.2.1 For the verification of strength properties of individual layers of laminates covered in Table 9.4.2.10, a series of tests of specimens representing types of reinforcement used in hull structure (mats, fabrics, unidirectional reinforcement). The tests shall verify the following parameters ε_{n1}, ε_{n2}, γ_{n12}, E_1, E_2, G_{12} for tension, compression and shear.

With this purpose, multi-layer specimens shall be prepared, with each layer uniform and corresponding to the verified layer. The test shall determine relevant modules *E* and *G* of specimens. The modules shall be specified at small range of relative deformations up to 0.003. The tests shall be performed in accordance with the requirements of chapter 6.2.

6.3.2.2 Parameters not higher than specified in the above tests shall be taken for strength calculations of hull structure acc. to chapter 9.4. Any departures from this condition require separate consideration by PRS.

6.3.2.3 PRS defines the scope of tests on the basis of hull structure documentation or the designer determined scope of used reinforcements. In justified cases and after separate consideration, PRS may depart from the requirement of testing some types of reinforcements or restrict the number of their verified parameters.

6.3.3 Control tests of laminate used for the construction of hull

6.3.3.1 In order to determine physical and mechanical properties of reinforced laminate used for the construction of hull, control plates, from which test specimens will be cut, shall be prepared during the same laminating process and with the same proportion of reinforcing material.

6.3.3.2 Preparation of test specimens

The control plate dimensions shall be ca. 400×500 × laminate thickness [mm].

Flat specimens shape and dimensions shall comply with the requirements of Chapter 6.3. The method of cutting specimens from the control plate shall be agreed with PRS.

The test specimens may also be cut from the material allowances of the laminated product or from areas intended for cutting. When it is technically reasonable, PRS may request cutting the specimens directly from the product itself.

The specimens shall be cut and subjected to testing after the period of time necessary to achieve full physical and mechanical laminate properties. The time period shall be specified by the resin manufacturer and agreed with PRS.

Determination of laminate properties by methods other than the mentioned in Chapter 6.3 shall be agreed with PRS.

6.3.3.3 Testing specimens cut from control plates shall include determination of:
- tensile, compression and shear strength,
- Young’s modulus *E* and modulus of rigidity *G*.

Selection of control plates and detailed scope of testing shall be agreed with PRS.

6.3.3.4 The above-mentioned strength properties shall be determined by testing on aged laminate specimens. The ageing tests shall be performed:
- according to 6.2.2.11.1 – for sea-water resistance, and
- according to 6.2.2.11.2 – for oil resistance.

6.3.3.5 Visual examination

Reinforced laminate products shall be free of laminations, blisters, foreign inclusions and other defects having an adverse effect on the product properties. If internal defects are suspected, PRS may recommend that the product be subjected to the appropriate tests, the scope of which shall be specially agreed with PRS.

6.4 Reinforcements

6.4.1 Fibres used for the reinforcements

.1 Reinforcements (fabrics, mats) made of the following fibres are accepted to the manufacture of hulls and superstructures of floating craft:

a) glass fibres:

– E type glass,
– S/R type glass,

b) carbon fibres:
– high-strength fibres HT/HS,
– intermediate module fibres IM,
– high-module fibres HM,

c) aramid fibres of high Young module.

.2 The use of other types of fibres shall be separately agreed with PRS.

6.4.2 Glass fibres

The E type glass fibre is the basic fibre commonly used in the manufacture of floating units. The S/R type fibres having better strength properties are used much less often.

Table 6.4.2
Chemical composition and properties of glass fibres used in the manufacture of composite reinforcements [1]

Components %	Type of glass			
	E	S	R	S2
SiO_2	63 – 72	65	54	64 – 66
TiO_2	–	–	0,2	–
B_2O_3	8	–	–	–
Al_2O_3	15	25	23 – 28	24 – 25
Fe_2O_3	–	–	0 – 0.5	0.1
BeO	–	–	0 – 0.5	–
MgO	4	10	3 – 8	9.5 – 10
CaO	18.5	0 – 0.3	8 – 15	0.02
$Na_2O + K_2O$	< 1	0 – 0.2	0 – 1	0 – 0.2
Strength properties				
Density [g/cm^3]	2.52	2.49	2.5	2.46
Tensile strength R_m [MPa] 1)	3500	4585	4750	4890
Modulus E [GPa]	77	85.5	86	86.9
Elongation at break ε_1 [%] 1)	4.8	5.7	4.8	5.2

1) The tensile strength R_m and elongation at break ε_1 given in the above Table refer to laboratory tests of single short fibres.
In practice, at testing long segments of fibres and fibre splits, the mean tensile strength R_m and elongations ε_1 are significantly lower. In the manufacture of reinforcements (fabrics, mats), the strength R_m and elongation of fibres is even more reduced due to damage of the fibres.

The preparation appropriate for the type of resins to be used in the manufacture of composite shall be marked on the surface of the glass fibres in the final product (fabrics, mats).

Reinforcements with preparations inappropriate for the type of used resins are not allowed.

6.4.3 Carbon fibres

3 types of carbon fibres are distinguished:

.1 the high strength (HT/HS) fibres – basic, most frequently used in the hull manufacture;
.2 the intermediate module (IM) fibres, of intermediate module and the highest strength;
.3 the high module HM fibres – of the highest Young's modulus and high strength.

Table 6.4.3
Strength properties of carbon fibres (Torayca)

Type of fibre		Specific weight [g/cm^3]	Tensile strength R_m [MPa]	Young's modulus [GPa]	Elongation at break [%]
HT/HS	T 300	1.76	3530	230	1.5

	T 700 S	1.80	4900	230	1.8
IM	T 800 H	1.81	5490	294	1.81
	T 1000 G	1.80	6370	294	1.80
HM	M 40	1.81	2740	392	0.7
	M 60J	1.93	3920	588	0.7
	M 40J	1.77	4410	377	1.2

The fibres have different diameters, are manufactured as roving/yarn with different numer of fibre in one split (3000, 6000, 12000, 24000).

6.4.4 Aramid fibres

The aramid fibres are known under trade names KEVLAR (USA) and TWARON (Netherlands) and are manufactured in various types. Only the high-module fibres, such as Kevlar 49, 149, are accepted for the manufacture of composite.

Table 6.4.4
Strength properties of aramid fibres

	Kevlar 49	Kevlar 149	Twaron HM
Density [g/cm^3]	1.44	1.47	1.45
Tensile strength R_m [MPa]	2800	2800	2800
Young's modulus [GPa]	124	186	125
Elongation at break ε [%]	2.5	1.9	2.0

6.4.5 Surface reinforcements

On the basis of fibres, surface reinforcements are manufactured in the form of fabrics, mats, etc.

6.4.5.1 Mats

Mats are manufactured by bonding of short (30 – 50 mm) segments (with accidentally laid fibre axes) of glass yarn (only E-glass).

Isotropic laminates are made of mats.

The use of mats bonded with styrene soluble powder binder is recommended, therefore only polyester and vinyl ester resins with ca. 40% styrene content may be used for mats supersaturation. Mats supersaturation with use of epoxy esin is not allowed.

6.4.5.2 Fabrics

.1 The use of fabrics made of one type of fibres and those made of various types of fibres is allowed.

Plain, diagonal and satin fabrics are distinguished considering weave. The fabric weave and surface density shall be selected taking into account hull curvatures and laminating procedure.

Where bends with large curvatures exist, the use of fabrics of lower surface density and satin or diagonal weave is recommended.

As regards strength, fabrics may be divided into fabrics with equal cross-section of fibres along warp or weft (balanced) and such fabrics where fibres cross-section is different, e.g. from ratio 1.5:1 to ratio 20:1 (unidirectional fabrics). The fibre cross-section along warp or weft depends on the amount of rovings per width unit (e.g. 100 mm) and on linear density of roving (warp and weft may contain roving of different linear density). The strength of composite made on the basis of fabrics is proportional to the cross-section of fibres along forces direction. Information on the structure of fabrics shall be submitted to PRS. Fabrics may have also the form of narrow stripes.

.2 The hybrid fabrics are normally woven of two types of fibres, where warp and weft may contain roving made of two types of fibres or the types of warp and weft roving fibres are different. When such fabrics are used, manufacturer's information of fabric construction is required, to include kind and type of fibres for warp and weft, fibres density, the number of rovings per 100 mm of fabric length and width and linear density (tex) of rovings in warp and weft.

.3 Hull structure drawings shall contain information on the direction of fabric warp. The same applies to unbalanced and unidirectional fabrics.

6.4.5.3 Multiaxial reinforcements

Multiaxial reinforcements sewn together from unidirectional layers laid at various angles with each other may be used to the construction of hulls and superstructures.

Biaxial reinforcements mean two unidirectional layers laid perpendicular with each other and at the angles 0°/90° or – 45°/45° to the warp axis.

Multiaxial reinforcements are sewn together several unidirectional layers laid at various angles with each other.

The reinforcements, especially those of high surface density, are rigid. When they are used, the hull curvature and laminating procedure shall be taken into account.

6.4.5.4 Unidirectional reinforcements

In addition to unidirectional fabrics (see 6.4.5.2), narrow (e.g. 300 mm) reinforcements composed of rovings stuck on foil and with mesh protection are allowed to be used. Their use shall be correlated with hull construction procedure. The reinforcements bring normally higher strength of laminate through less damage to fibres (no woving) and higher content of reinforcement in the laminate.

6.4.5.5 Other kinds of reinforcement

Other kinds of reinforcement, such as three-dimensional reinforcements, shall be considered separately by PRS.

6.4.5.6 Tests of reinforcing materials

6.4.5.6.1 The reinforcing materials shall be subjected to examination determining:
– the moisture content, in accordance with ISO 3344[1)] – not exceeding 0.2% at delivery,
– the loss on calcination, in accordance with ISO 1887[2)] – tolerance ±10%,
– the linear density (mass for unit area):
  – for roving, in accordance with ISO 1889[3)] – tolerance ±10%,
  – for mats, in accordance with ISO 3374[4] – tolerance ±10%,
  – for woven roving, in accordance with ISO 3374 – tolerance ±10%.

6.4.5.6.2 When approving the glass reinforcements, the testing of the properties of laminate containing the reinforcement shall be carried out in accordance with 6.3.

The type of resin used for laminate specimens shall be agreed with PRS.

6.5 Resins

6.5.1 Properties of resins bonding fibre reinforced laminates

As regards the laminate strength which can be ensured by reinforcing fibres, the resin shall have the following properties:

1. Relative tensile elongation at break higher than elongation breaking the fibres. When the resin has relative elongation less than the fibre, the laminate under tension breaks at the break of resin and the fibre properties are not fully utilized, thus the laminate strength (R_m) is reduced.
2. High Young's modulus *E* of resin within high range of relative deformations. At laminate compressive stress along fibres, with elastic resin, the fibres are normally subject to buckling and low modulus E reduces the compression strength.
3. High tensile elongation at break of resin. It is also essential at laminate tension perpendicular to fibre axis. Due to significantly lower rigidity of resin (module *E*) locally between fibres, the relative

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1) ISO Standard 3344:1997 Reinforcement products – Determination of moisture content.
2) ISO Standard 1887:2014 Textile glass – Determination of combustible-matter content.
3) ISO Standard 1889:2009 Reinforcement yarns – Determination of linear density.
4 ISO Standard 3374:2000 Reinforcement products – Mats and fabrics – Determination of mass per unit area.

elongation of resin is many times higher than laminate elongation and the resin cracks or loosens in these spots.
4. Good fibre – resin adhesion, deciding on forces transfer between fibres.
5. High temperature of rigidity and strength loss (in particular at bending and compression). It allows for better protection of structure against heat in normal service and from fires.

Due to technological reasons, resin shall have the following properties:

1. Low hazard to health and environment, in particular at the stage of laminating.
2. Viscosity and tixotropy appropiate for applied reinforcement and used laminating procedure.
3. Long pot life appropriate for laminate thickness and laminating procedure.
4. Possibly low temperature of exothermic peak during gelation, allowing for single high thickness laminating.
5. Possibly high speed of laminate post-cure, allowing for shorter stay of laminate in the mould.

6.5.2 Unsaturated polyester resins

Polyester resins are the condensation polymer chain. Mixtures of relevant resins with monomers create the commercial product.

The polyester resin properties are influenced mainly by their chemical composition (acid part and glycol part). Regarding the acid part of polyester, the following resins are manufactured:

– orthophtalic – basic resins, give laminates of medium quality, produce large amounts of fume when burned;
– isophtalic – better in quality than the orthophtalic, show better water-, chemicals- and elevated temperature resistance;
– terephtalic – ensure higher water and heat resistance, higher strength of laminates;
– HET acid based – give self-extinguishing properties to laminate, toxic compound (HCL) is emitted during burning;
– other.

Glycol part of polyester resins means among the others:

– propylene glycol (emits large amounts of fume during burning laminates);
– neoprene glycol (allows to gain hydrophobic resin of higher water- and chemo-resistance and elevated temperature resistance);
– hydrated diane – ensures better chemical and thermal resistance;
– others.

Styrene is commonly used as monomer. It is cheap, however, flammable and toxic.

Other chemical compounds creating better resin properties than styrene, may also be applied as monomers.

Curing polyester resins consists in copolymerization of oligoester with monomer resulting in building monomer particles into oligoester chains, thus creating three-dimensional net. The reaction occurs under the influence of free-radical initiators (called hardeners) such as benzoyl peroxide, methyl ethyl ketone hydroxide and other, with the addition of accelerants such as cobalt salts or appropriate amines. The cross-linking of polyester is an exothermic reaction, and due to emitted heat thickness of laminate manufactured within one cycle must be reduced. The amount of initiator and accelerator and laminating temperature have strong influence on the time the resin is liquid and it may be used for laminating.

6.5.3 Vinyl ester resins

The vinyl ester resins are the result of epoxy resin reaction with unsaturated acids, e.g. diane epoxy resin and acrylic acid. After adding monomer (up to 50%), a binder is created cured similar to polyester resins. However, its different structure ensures better mechanical properties, higher thermal and chemical resistance and adhesiveness.

The vinyl ester resins have good technological properties, ability of adjusting viscosity (by temperature), ability of thixotropicity, extending gel time (pot life), reducing reactivity is also possible.

With good adhesion, the resins have good saturability of glass, carbon and aramid fibres.

6.5.4 Epoxy resins

Epoxy resins have various chemical structure. Resins based on bisfenol and glycerine epichlorohydrin are mostly used for the manufacture of composites. In order to reduce viscosity, active diluters, which integrate with the cured resin structure, or inactive diluters (e.g. styrene), which reduce resin properties, are often added. Curing epoxy resin requires adding the hardener.

A number of hardeners exists. Some shall be added in strictly specified amounts, depending on the type of resin, other may be added in different proportions, thereby modifying properties of the hardened binder.

By the hardener selection, the usage time of the resin mixed with hardener can be modified to significant extent (e.g. from a dozen of minutes to a dozen of hours). The usage time depends also on laminating temperature – with lower temperature the time lengthens but the resin viscosity raises. Heating laminate immediately after its curing has effect on the resin properties, in particular the increase of thermal resistance. It applies to a various degree to different combinations of resin and hardener. In general, the higher heating temperature, the higher laminate durability loss temperature. Heating laminated hulls together with their mould is strongly impeded due to large sizes.

6.5.5 Tests of polyester resins

6.5.5.1 The requirements apply to unsaturated, vinyl and epoxy polyester resins, used for the manufacture of products subject to PRS supervision.

PRS approved resin types shall be used as structural resins in the manufacture of reinforced laminates.

6.5.5.2 Scope of tests

6.5.5.2.1 Liquid polyester resins shall be subjected to the testing determining:

- density, in accordance with ISO 1675[1] – for conformity with the manufacturer's specification,
- viscosity, in accordance with ISO 2555[2] – tolerance ±20% in relation to the manufacturer's specifications,
- acid value, in accordance with ISO 2114[3] – tolerance ±10% in relation to the manufacturer's specification,
- volatile material content, in accordance with the procedure agreed with PRS –tolerance ±10% in relation to the manufacturer's specification,
- gel time, in accordance with ISO 2535[4] – tolerance ±20% in relation to the manufacturer's specification,
- overall volume shrinkage during curing, in accordance with ISO 3521[5] – for conformity with the manufacturer's specification.

6.5.5.2.2 The cured structural resins shall be subjected to the test determining:

- density,
- hardness, in accordance with EN 59[6] – not less than 35 in Barcol scale,
- temperature of deflection using a flexural stress of 1.8 MPa in accordance with ISO 75-2[7] – not lower than 60 °C, but also not lower than specified in 10.2.6.5 for fire divisions,
- water absorption (in accordance with 6.2.2.10.1 using the specimens of the following dimensions: 50 ±1 x· 50 ±1 x· 4 ±0.2 mm within 28 days) – not exceeding 80 mg,
- tensile strength (in accordance with 6.2.2.5.1) – not less than 50 N/ mm^2,
- modulus of elasticity (in accordance with 6.2.2.5.1) – not less than 3000 N/mm^2,
- elongation at break (in accordance with 6.2.2.5.1) – not less than 2%.

The postcure of resins at a temperature of 40 °C for 16 hours and subsequent stabilizing at the room temperature for 24 hours may be accepted. Other postcure conditons are subject to separate agreement with PRS.

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1) ISO Standard 1675:1985 Plastics – Liquid resins – Determination of density by the pyknometer method.

2) ISO Standard 2555:1989 Plastics – Resins in the liquid state or as emulsions or dispersions – Determination of apparent viscosity by the Brookfield Test method.

3) ISO Standard 2114:2000 Plastics (polyester resins) and paints and varnishes (binders) – Determination of partial acid value and total acid value.

4) ISO Standard 2535:2001 Plastics – Unsaturated-polyester resins – Measurement of gel time at ambient temperature.

5) ISO Standard 3521:1997 Plastics – Unsaturated polyester and epoxy resins – Determination of overall volume shrinkage.

6) EN Standard 59:2016 Glass reinforced plastics – Determination of indentation hardness by means of a Barcol impressor.

7) ISO Standard 75-2:2013 Plastics – Determination of temperature of deflection under load– Part 2: Plastics and ebonite.

6.5.5.2.3 Gel coat resins shall not contain more than 15% of pigments and fillers and shall make the covering of 500 μm maximum thickness.

6.6 Strength properties of laminates

6.6.1 The strength properties of laminates depend on many material, structural and technological factors. The basic factors are as below:
- type of fibres (as regards material) and their strength,
- volume content of fibres in the composite, depending mainly on applied manufacturing procedure,
- fibres direction in relation to composite loading forces,
- arrangement of laminate layers both when different types of fibres and different forms of reinforcement made on the basis of the same fibre (e.g. mat, fabric, unidirectional reinforcement) are used.

6.6.2 Minimum properties

The minimum values of strength properties of fibreglass based laminates (E-glass) amount to:
- tensile strength – 80 MPa,
- modulus of elasticity in tension – 7 GPa,
- flexural strength – 135 MPa,
- flexural modulus – 6 GPa,
- glass fibre content – 25%.

6.6.3 Laminate properties

Standard, easily technically obtainable strength properties of laminates reinforced by mats, biaxial fabrics, mats and fabrics laid alternately in layers, unidirectional fabrics based on E-glass or carbon HT/HS and aramid fabrics, are given in Annex C to PN-EN ISO 12215-5.

6.6.3.1 Properties of fibreglass based laminates

Table 6.6.3.1-1
Strength properties of laminates reinforced by mats and balanced E-glass based fabrics (fibres laid at angles 0° – 90° to specimen sides)

Content		R_m	R_c	R_g	R_t	E	G
by mass	by volume	[MPa]				[GPa]	
0.250	0.135	67	110	138	58	4.50	2.665
0.275	0.151	76	113	145	60	5.45	2.708
0.300	0.167	85	117	152	62	6.40	2.750
0.325	0.184	96	121	160	64	7.35	2.793
0.350	0.202	107	125	168	66	8.30	2.835
0.375	0.220	120	128	178	68	9.25	2.878
0.400	0.238	133	132	187	70	10.20	2.920
0.425	0.257	148	136	198	72	11.15	2.963
0.450	0.277	163	140	209	74	12.10	3.005
0.480	0.302	183	144	223	76	13.24	3.090
0.500	0.319	197	147	233	78	14.00	3.090
0.525	0.341	216	151	245	80	14.95	3.133
0.550	0.364	235	155	259	82	15.90	3.175
0.575	0.388	256	158	273	84	16.85	3.218
0.600	0.413	277	162	288	86	17.80	3.260

where:
R_m – tensile strength;
R_c – compression strength;
R_g – flexural strength;
R_t – shear strength;
E – Young’s modulus of elasticity;

G – modulus of rigidity.

Higher content of fibreglass apply to reinforcement by fabrics alone.

For small content of fibreglass in laminate, properties of used resins are more important, and that is evident in R_m and R_c rates for small (mat reinforcement) and large (fabric reinforcement) content of glass in laminate.

The properties of laminate made on the basis of S/R glass fabrics are generally higher. Precise data are lacking due to infrequent use of such fibres. It may be assumed by estimation that for the same content modules are by 15 – 20% higher, strength by 30 – 60% higher, compared to E-glass based laminates.

Table 6.6.3.1-2
Strength properties of laminates with unidirectional E-glass based reinforcement (loads along fibres)

Content		R_m	R_c	R_t	E
by mass	by volume	[MPa]			[GPa]
0.400	0.238	337	290	50	17.586
0.425	0.257	358	296	50	18.727
0.450	0.277	381	303	50	19.927
0.480	0.302	405	309	50	21.184
0.500	0.319	430	315	50	22.500
0.525	0.341	456	321	50	23.874
0.550	0.364	483	328	50	25.307
0.575	0.388	511	334	50	26.797
0.600	0.413	541	340	50	28.346

6.6.3.2 Properties of carbon fibre based laminates

The strength properties of carbon fibre based laminates are shown in the below tables.

Table 6.6.3.2-1
Strength properties of carbon based laminates (HT/HS fibres) reinforced by fabrics laid at angles 0° – 90° to specimen side

Content		R_m	R_c	R_t [1)]diagonal	R_t	E	G
by mass	by volume	[MPa]				[GPa]	
0.400	0.308	306	189	188	47	31.0	5.1
0.425	0.330	331	204	192	48	33.0	5.1
0.450	0.353	356	220	196	49	36.0	5.1
0.475	0.376	380	235	200	50	38.5	5.1
0.500	0.400	405	250	204	51	41.0	5.1

[1)]Shear strength for diagonal arrangement of fibres (± 45°)

Table 6.6.3.2-2
Strength properties of carbon based laminates for unidirectional reinforcement (HT/HS fibre)

Content		R_m	R_c	E	R_m	R_c	E
by mass	by volume	[MPa]		[GPa]	[MPa]		[GPa]
		load along fibre			load transverse to fibre		
0.400	0.308	600	330	59.80	20	60	4.43
0.425	0.330	650	358	64.85	21	62	4.55
0.450	0.353	700	385	69.90	21	63	4.68
0.475	0.376	750	413	74.95	22	65	4.85
0.500	0.400	800	440	80.00	23	68	4.98

The properties of laminates reinforced by IM/HM fibres are approximately proportional to fibre module E and R_m. The module E of laminate is proportional to module E of the fibre, R_m of laminate are proprtional to R_m of the fibre, compression strength does not depend on tensile strength – compressed fibres are subject to buckling, therefore increase of strength R_m of the fibre does not influence R_c of laminate.

6.6.3.3 Properties of aramid laminates

For manual laminating of balanced fabric with fibres laid at angles 0° – 90°, the properties of aramid laminates for mass content 0.3 and 0.4 are given in the below table.

Table 6.6.3.3
Properties of fabric reinforced aramid laminates

	Unit	Fibre mass content	
		0.3	0.4
Tensile strength (R_m)	MPa	196	268
Compression strength (R_c)	MPa	75	100
Interlaminar shear strength	MPa	45	45
Modulus of elasticity (E) along fibres	GPa	15.75	20.75
Module G	GPa	3.4	3.4

The above table shows parameters which can be achieved at ordinary workmanship and standard technology.

6.6.3.4 Hybrid laminates

Glass-carbon reinforced laminates show intermediate strength properties in relation to uniform laminates, depending on the content of particular fibres, fibres to forces lay-out, the kind of reinforcement (biaxial – unidirectional).

The flexural and compression strength of carbon/glass aramid reinforced laminates is significantly better than that of pure aramid laminates. Use of pure aramid laminates for compressed or bent elements is not recommended. The impact strength of aramid fibre reinforced laminates is generally higher compared to E-glass reinforced laminates and in particular carbon laminates.

6.7 Sandwich structures

6.7.1 Definitions

Sandwich structure – normally triple-ply plate with external layers being thin monolithic laminate linings while the binding middle layer is built of many times thicker and lighter material.

Core – the middle part of the sandwich plate, normally built of light material.

6.7.2 Load transfer in sandwich plate

For loads due to pressure perpendicular to plate surface, the bending moments are transferred by normal stresses in laminate linings.

The core participates in bending moment transfer to minimum extent, while it transfers almost in whole the shear force.

The forces in sandwich plate plane are transferred mainly by laminate linings.

6.7.3 Kinds of core materials

Cores are built of the following materials:

1. Balsa wood – normally joined together bars of impregnated wood of specified thickness cut with trunk axis perpendicular to the core plane.
2. Rigid foams – normally PVC plates.
3. Honeycomb fillers (Nomex or hexagonal or rectangular cells).
4. Other, e.g. Coremat, etc.

6.7.4 Strength properties of core materials

Typical strength properties of cores depending on density specified in *EN ISO 12215-5.2008 Standard (Annex D)* are shown in the below Table.

Specific mass	R_t	G	R_c	E_c
g/cm^3	MPa	MPa	MPa	MPa
Balsa				
90	1.26	77	4.2	1413
100	1.44	85	5.2	1720
120	1.80	103	7.2	2334
150	2.33	129	10.3	3255
180	2.86	155	13.4	4176
200	3.22	172	15.4	4790
220	3.58	190	17.4	5404
Rigid PVC foam				
54	0.63	17.1	0.66	47
72	0.93	23.1	1.11	68
90	1.24	29.0	1.56	90
120	1.75	38.9	2.31	126
145	2.18	47.2	2.94	156
180	2.77	58.7	3.81	198
Linear PVC foam				
60	0.51	12	0.48	31
70	0.65	15	0.60	40
80	0.79	18	0.72	48
100	1.07	24	0.96	65
140	1.63	35	1.44	99
SAN foam				
60	0.34	8	0.45	31
70	0.48	12	0.58	41
80	0.62	17	0.71	51
100	0.89	26	1.01	76
130	1.26	40	1.54	120
150	1.49	49	1.93	154
200	1.99	72	3.05	255

where:

- Balsa – see 6.7.3;
- Rigid PVC foams – cross-linked PVC foams based on isocyanate, such as HerexC, Divinycell H i HT, Klegocell;
- Linear PVC foam – such foams as Airex R 63.80 or Divinycell;
- SAN foam – PMI foam made from styrene copolymer – acrylonitryle, e.g. ATC Core-Cell A.

7 TECHNICAL SUPERVISION PROCEDURES

7.1 The basis for construction survey are:

- supervision documentation approved by PRS Head Office,
- workshop documentation agreed by PRS Surveyor attending the construction,
- test certificates/approval certificates for materials/products issued by PRS,
- PRS Rules (*Rules*) and PRS Publications (*Publications*),
- PRS Directives,
- international conventions,
- construction survey contract.

7.2 The construction survey covers the whole hull structure, together with:

– superstructures and deckhouses,
– propeller shaft tunnels,
– seatings for main engines,
– seatings for auxiliary engines and mechanisms, and associated machinery components subject to PRS' survey,
– shaft brackets, fixed propeller nozzles,
– coamings, companionways and other boundaries of openings in hull
– movable ramps and platforms.

7.3 During construction, the structures, listed in 7.2, are subject to survey with regard to:

– compliance with the approved technical documentation,
– compliance with the requirements of the present Publication within the scope not indicated in the technical documentation,
– compliance with the requirements specified in Chapter 6 – Materials used for the manufacture of laminates.

7.3.1 It is recommended to set and systematically maintain the *Construction Log*, where records related to construction phases are made and confirmed by PRS Surveyor.

7.3.2 After construction completion, the Surveyor enters in the *Construction Log* a record defining the scope and result of the performed survey. The record, supplemented with notes made during construction, is a final document from the survey of the unit construction, carried out by the Surveyor.

7.4 The below construction stages are given as a framework, with the meaning that the activities mentioned in .1 to .8 may be combined in different ways, taking into account demands of the organization and technology used in the given construction.

.1 the inspection and acceptance of construction site, inspection of materials and acceptance of their storage, inspection of hull laminating mould,
.2 control of laminate manufacture during hull laminating,
.3 acceptance of plating after lamination and acceptance of the performance of plating shell stiffeners and of shell laminating, as well as control of test results of the specimens taken from control plate or from hull and deck plating,
.4 acceptance of hull and deck after their mounting together and acceptance of performance and assembly of the unit equipment elements, e.g. rudder blade,
.5 checking correctness of the installation of machinery, electrical appliances and pipings,
.6 acceptance of the fully equipped unit,
.7 attendance in stability test,
.8 attendance in operational tests.

8 CONSTRUCTION FROM LAMINATE TECHNOLOGY

8.1 General

8.1.1 The subject of this Chapter shall define the conditions and method of forming products of polymer composites.

8.1.2 Any laminate elements shall be performed in accordance with construction documentation.

8.1.3 The surface layer – gelcoat, with decorative and utility functions, shall be continuous, smooth, shiny, of uniform thickness (0.6÷0.8 mm) and colour, free of scratches, splinters, air blisters and intrusions.

8.1.4 The structural layers of laminate shall tightly and durably adhere to gelcoat, be free of blisters, laminations and fraying fibres, therefore at laying each laminate layer all process regime shall be maintained.

8.1.5 Internal sides of laminate shall be protected with top-coat layer.

8.1.6 The number of laminate layers, the kind, type and surface density of the reinforcement, the sequence of coating shall be specified in the approved construction documentation. All reinforcing elements shall be laminated to the structure layer in accordance with the approved documentation.

8.1.7 It shall be assumed that workshop conditions have considerable effect on short-duration and long-term properties of the floating unit and that the manufacture is executed in conditions appropriate for the used material and using appropriate manufacturing process.

8.2 Storage of raw materials

8.2.1 All construction materials received in the manufacturing plant shall be checked for their usability (type, validity, manufacturer, etc.). Outdated materials may not be accepted for manufacture.

8.2.2 Each stored material/raw material shall be durably marked, to be fully identifiable.

8.2.3 The manufacturing plant shall have developed and implemented procedures for acceptance of materials, verifying compliance certificates, storage of materials and their handling; the procedures shall be specified in conformity assurance procedures developed by the unit manufacturer and shall guarantee that the materials will not be polluted and their quality will not worsen and that they will all the time be marked so that to be identifiable. At the storage of production materials, their manufacturers' recommendations specified directly on packaging or in material sheet shall be observed.

8.2.4 Material storage shall be organized so that materials are kept in original packagings in dry, free of dust spaces and that they are taken to production in the sequence of their delivery to storage, if it is possible.

8.2.5 Resins and their additives shall be stored in hermetic containers, in a place without access of light and in the temperature recommended by the manufacturer, preferably adjacent to manufacturing space. The resin storage period shall not exceed its warranty period.

8.2.6 Reinforcement materials shall be stored in original packages in dry and dust-free spaces.

8.2.7 If material defects and non-conformities with deliverer specification are found, such material shall be rejected unless it is subjected to relevant activities, in accordance with manufacturer's procedure for conformity assurance.

8.2.8 All the materials, prior to their use, shall be brought to the temperature similar to the temperature existing in the production space. Non used resin and auxiliary materials, exposed to workshop atmosphere, shall not be returned to previous storehouse.

8.3 Production space

8.3.1 In respect of size and type of production, the production space shall be properly separated from the storage spaces. Various cycles of the construction process (such as: preparation of resin, reinforcement cutting, laminating) shall be carried out in separate but adjacent spaces.

8.3.2 Production space shall enable to maintain constant temperature within l6– 24°C. In exceptional cases the temperature can be lowered to 12°C but not during laminating or gelation of any structural part of the hull and not earlier than 12 hours after resin gelation. Period of time of lowered temperature shall be minimized with respect to the construction weight and the period of time from the latest lamination.

8.3.3 Production space floor shall be clean and shall not emit the dust. It shall be kept as clean as practicable. The air in the space shall be dust-free. Particularly the dust of substances affecting the polymerisation process or separating the laminated parts shall be avoided. Dust emitting machines cannot be used in the production space.

8.3.4 The relative humidity in the space shall not, in general, exceed 70 - 75 per cent. For short periods of time, the relative humidity up to 85 per cent can be accepted.

8.3.5 Continuous temperature and humidity control in the production space shall be provided.

8.3.6 Appropriate ventilation shall be ensured in the area of lamination process, to maximally restrict accumulation of monomer vapours in the mould. Ventilation shall not considerably reduce the temperature of mould nor that of laminate. Ventilating system used in the production space should not cause excessive vaporisation of styrene.

At designing ventilation system, the size of the space, its division and the amount of resin to be cured shall be considered.

8.3.7 Laminated elements shall be protected against sun radiation.

8.3.8 The workshop and its equipment shall be clean, free of rubbish and wastes, unnecessary materials and of the equipment not used in the manufacturing process.

8.4 Moulds

8.4.1 Materials used for moulds cannot affect the resin polymerisation process.

8.4.2 The moulds shall be of sufficient rigidity and their shape shall enable easy removal of the moulded part from the mould. They shall be clean, dry and be kept in the laminating space to have stabilized workshop temperature, before application of the separating layer.

8.4.3 Big moulds shall be provided with proper stagings enabling access to the whole laminated surface.

8.4.4 It is recommended, particularly for bigger hulls, to use rotable (or swinging) moulds, in order to enable the downhand laminating.

8.4.5 Used separating means shall be compatible with the mould surface and with resins used in laminating. Separating means which contain silicon may not be used.

8.4.6 Construction of yachts without hull moulds ("one-off" technology) shall be considered by PRS individually.

8.5 Laminating

8.5.1 General

8.5.1.1 Resin for gelcoat and for structural layers of laminate shall be prepared according to the manufacturer's recommendations.

8.5.1.2 Gelating time of the resin shall not exceed 1 hour. Each alteration of gelating time shall be controlled by alteration of accelerant quantity without altering the recommended quantity of the initiator.

8.5.1.3 Glass reinforcement shall be used in as large sections as possible. It is recommended to use mats with torn out rather than cut out edges.

8.5.1.4 Continuous control of resin-reinforcement proportion shall be ensured during the whole laminating process. When preparing the glass mates for lamination process, the mass of binder shall be taken into consideration (the binder mass shall be subtracted from the total mass of the reinforcement).

8.5.1.5 Prior to beginning the hull plating laminating, the moulds shall be thoroughly cleaned, dried and brought to the space temperature. The lutes used for maintenance of the moulds and the separating agents cannot react chemically with the resins.

8.5.1.6 Gelcoat layer can be put on with the use of brush, roller or spraying device. Generally, the gelcoat layer thickness shall be within 0.4 – 0.6 mm.

8.5.1.7 Gelcoat layer, after a period of time not longer than 6 hours (after hardening), shall be coated with the first layer of the laminate reinforced with light fabric or mat of surface mass not greater than 300 g/m^2. This layer should be particularly well deaerated, the glass content being 20 - 30 per cent.

8.5.2 Manual laminating

8.5.2.1 Manual laminating of proper structural layers shall be made using soft and hard rollers and brushes.

8.5.2.2 Laminating shall be carried out without pauses ("wet to wet"). If the pauses occur and are longer than 24 h, the contact surface should be properly prepared by grinding or by putting on formerly a poly-amide fabric, which shall be torn off before the next layer is laid on.

8.5.2.3 The successive layers of reinforcement shall be laid on without waiting until the resin of the former layer becomes hardened. Too great number of laminate layers should not be laid because this can produce overheating of the laminate.

8.5.2.4 If laminating is stopped in such a moment that the last resin layer has been already hardened, then the first of the successive layers should be begun with the glass mat. It is also recommended to use mat for the last layer of laminate in the bottom area.

8.5.2.5 Reinforcement overlap width of the same layer shall not be less than 50 mm. The overlaps should be shifted in relation to these belonging to other layers by at least 100 mm.

8.5.2.6 Steps of the reinforcement content in the laminate shall not exceed 600 g/m^2 for each 25 mm of the transient band width.

8.5.2.7 Edges of materials such as wood, plywood, metals and core foams, laminated into the plating, shall be tapered.

8.5.3 Technologia laminowania metodą natryskową

8.5.3.1 Spraying method of resin and/or reinforcement application should be generally restricted to the cases where uniform thickness of laminate may be achieved. The following factors shall be considered:
– exothermic excretion of heat due to excessive thickness of wet laminate,
– laminate settlement or drip, and
– deaeration.

8.5.3.2 It is recommended to use the spraying method at application of the first layer of laminate directly on gelcoat. The type and length of reinforcement shall be so chosen to avoid the „wick effect".

8.5.3.3 The weight of glass reinforcement to be laid in one layer depends on the mould structure. The reinforcement should not generally exceed 1150 g/m^2, unless it has been proved that proper laminate may be achieved with the use of bigger mass of reinforcement.

8.5.3.4 Uniformity of laminate and glass content shall be regularly checked.

8.5.3.5 The spraying device shall be calibrated. At the beginning of each workday, the device setting ensuring proper resin-initiator and resin-reinforcement proportions shall be controlled. Settings shall be controlled to ensure maintaining spray within tolerance limits.

8.5.4 Laminating by vacuum method

8.5.4.1 Infusion procedure of manufacturing composite materials is a process used mainly in manufac-ture of large objects, such as hull and yacht hulls.

8.5.4.2 Vacuum infusion consists in saturation of dry reinforcement placed in closed mould with liquid resin, where the upper rigid part of the mould is replaced with elastic foil and the resin is not forced but sucked by the mould interior vacuum.

8.5.4.3 The infusion process and its method of execution are able to be modified, therefore they are in each case subject to consideration.

8.5.4.4 Each product must be considered on individual basis. For the given product, the resin supply and deaeration systems shall be each time newly designed, to ensure full filling of the mould.

8.5.4.5 During application of preforms, they shall be thoroughfully adjusted to the mould, the surface of which has been coated with separating agent. During this operation, the reinforcement structure may be subject to slight deformation by a small angle, and in result the reinforcing material layers adjust to the mould surface shape.

8.5.4.6 Gluing sealing tapes, application of foil, gluing in openings for resin supply and deaeration of the mould interior and connecting to the vacuum and resin supply system shall be performed carefully to ensure the mould tightness and to achieve product of high functional properties.

8.5.4.7 During infusion process, resin flow shall be controlled, e.g. by ensuring the possibility of valves opening/closing, where reasonable. The pressure at vacuum pumps shall be properly set, considering the product size and complexity.

8.5.4.8 The mould tightness shall be checked by means of acoustic detectors, and any leak shall be efficiently removed.

8.6 Performance requirements for sandwich structures

8.6.1 Sandwich structures using concave forms

8.6.1.1 Cavities on the core surface and other defects shall be removed or supplemented with filler, resin or binder, in accordance with material manufacturer specification and considering the type of applied coating. If the core material has pits, appropriate amount of resin or binder shall be used to fill the gaps.

8.6.1.2 If core material is bound with wet laminate, appropriate amount of resin shall be ensured in the laminate or on its surface for proper binding laminate with core material and to avoid resin deficiency in the laminate.

8.6.2 Sandwich structures using convex forms

8.6.2.1 Prior to application of laminate, joints, pits and void spots in core material shall be filled or adjusted.

8.6.2.2 During coating the core material, it shall not be so flexured or deformed that the core properties could be impaired. Irregularities of core surface and joints shall be removed.

8.6.2.3 Where required, the core surface shall be primed before laminating.

8.6.3 Departures form the specified procedures are allowed if design requirements given in the approved laminating procedure are complied with.

8.7 Hardening

8.7.1 Upon the completion of the laminating, the hull parts shall be left in the moulds for the time necessary for initial hardening of the laminate. This time cannot be shorter than 24 hours.

8.7.2 Parts removed directly from the moulds shall be properly supported or joined with other parts in the way preventing their distortion before acquiring the proper rigidity.

8.7.3 Upon the completion of the laminating, the hull parts shall be left in the production space or other room of temperature not less than 16°C, until a proper hardness (about 35 - 40 acc. to Barcol) is attained. If the hardness cannot be measured, then the hardening time may be assumed as:

30 days in 16°C
15 days in 25°C
15 hours in 40°C
9 hours in 50°C
5 hours in 60°C.

Heating of the laminate structure is recommended. Abrupt changes of the temperature should be avoided. Gradual raising of the temperature shall be carried out according to the resin manufacturer's recommendations. The air in the heating room shall be properly dried /4.2.4/ and the hull shall be properly supported during the heating process. The thermal resistance temperature of laminate or core foam used for the yacht construction must not be exceeded.

8.8 Quality control

8.8.1 The whole laminating process shall be constantly controlled by the works quality control system for the compliance with:

– the requirements of 8.1 – as regards storing of materials,
– the requirements of 8.2 – as regards production spaces,
– the requirements of 8.3 and 8.4 – as regards laminate moulding and curing process,
– the approved classification documentation – as regards succession, type and number of put-on glass reinforcement layers,

In the case of disclosed defects, the corrective means shall be taken as defined in the works procedures.

8.8.2 At the completion of all essential stages of construction, designated employee shall accept them and make appropriate record in the product construction sheet and that shall be endorsed by the PRS Surveyor.

8.8.3 A control panel shall be made at selected stages of construction in the time of laminating. The control panel shall be subject to material tests in an external laboratory approved by PRS, with the purpose to determine quality of laminates manufactured in the works. The test report shall contain the following:

Properties of hardened laminate	Test acc. to Standard
– glass reinforcement content,	PN-EN ISO 1172
– tensile strength, [MPa]	PN-EN ISO 527-1, -5
– Tensile Young's modulus, [MPa]	PN-EN ISO 527-1, -5
– bending strength, [MPa]	PN-EN ISO 178
– Bending Young's modulus, [MPa]	PN-EN ISO 178
– hardness acc. to Barcol	ASTM D 2583-87

8.8.4 A control panel should have dimensions of 400 x 500 mm. Its construction and thickness should exactly correspond to the amidships plating laminate. The control panel hardening process shall be identical with the yacht's hull hardening and using the same materials. After having agreed that with PRS Surveyor, pieces of plating obtained while cutting out significant holes can be regarded as samples.

8.8.5 Where necessary, the specimen tests may be extended by water absorptivity, flammability tests as well as fuel oil, sea water and UV radiation resistance tests.

9 HULL

9.1 General

9.1.1 Definitions and symbols

9.1.1.1 Co-ordinate system

In the present *Publication*, the co-ordinate system, shown in Fig. 9.1.1.1, has been assumed for ships. The following reference planes have been assumed for the system: base plane, centre plane and midship section.

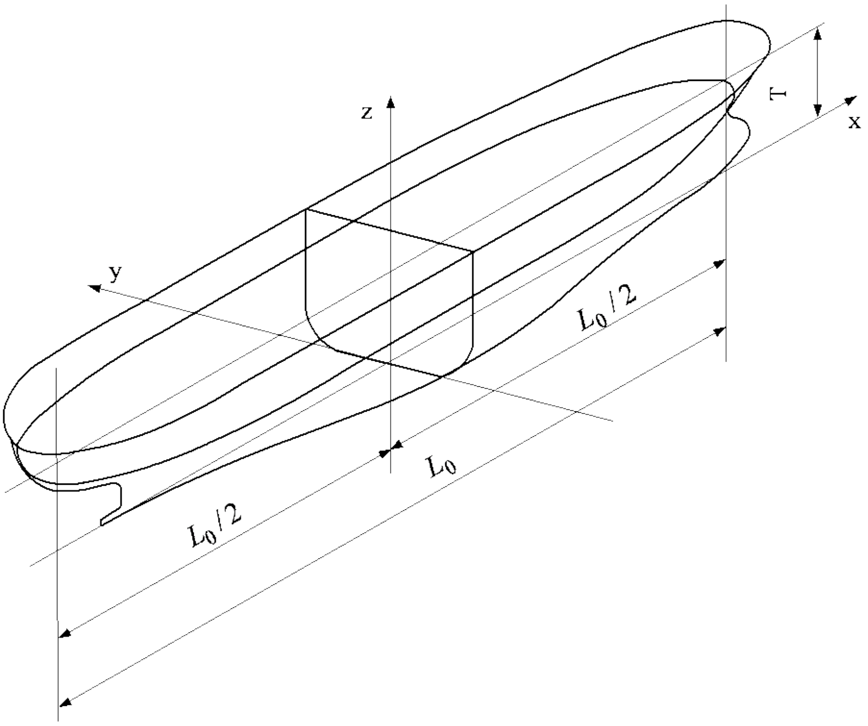


Fig. 9.1.1.1. Co-ordinate system

The intersection of the centre plane and the base plane forms *x* axis of the positive sense forward

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

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

Other ship co-ordinate systems, specified separately, are also applicable to the present *Publication*.

9.1.1.2 General terms

In Chapter 9, general definitions and terms contained in Chapter 2 and the below terms and symbols contained in particular subchapters of this Chapter apply.

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

L_W – length of summer load waterline, [m] – the distance measured at this waterline from the fore side of the stem to the point of intersection of the waterline with after side of the stern (transom).

FP – forward perpendicular – the vertical line at the ship centre plane at the intersection of the summer load waterline with the fore side of the stem. For ships with unconventional stem curvature, the position of the forward perpendicular is subject to PRS acceptance in each particular case.

BP – base plane – horizontal plane which crosses amidships the top of a flat keel or the intersection of the inner surface of the plating with the bar keel.

AP – after perpendicular – the perpendicular at the ship centre plane, at distance L_0 from *F.P.*, in aft direction.

CP – ship centre plane.

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

x, y, z – co-ordinates of a point in the ship, [m] – see 9.1.1.1

δ – moulded block coefficient – the coefficient calculated in accordance with the below formula:

$$\delta = \frac{V}{L_0 BT}$$

v – ship speed [knots] – the maximum service speed at draught T.

Summer load waterline – the waterline corresponding to the Summer Load Line defined in accordance with the Regulations of the *International Convention on Load Lines, 1966*.

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, without rounding.

Midship section – a curve being the result of hull surface cross-section with the vertical plane normal to the centre plane, situated in the middle of length L_0.

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 an extension of the forecastle or the poop.

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 midship superstructure deck in question). Any other deck may be defined as the strength deck within the given length of the ship subject to PRS acceptance of continuity of the ship's sides with respect to shear strength in each particular case.

9.1.1.3 Definitions of structural members

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

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

Side structure – shell plating, including stiffeners and primary supporting members, 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 primary supporting members.

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

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

Superstructure (deckhouse) structure – superstructure (deckhouse) wall and deck plating, including the stiffeners and primary supporting members.

Deck structure – deck plating, including stiffeners and primary supporting members.

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

Structural members – a general term used for such ship structures as the plating, the plating stiffeners and primary supporting members.

Primary supporting members – a general name for structural members supporting stiffeners or the stiffener systems.

Main frames – side frames located outside the peak 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.

9.1.2 Classification documentation of ship's hull under construction

Prior to beginning the construction of the ship's hull, the below documentation shall be submitted to the PRS Head Office for consideration and approval within the applicable scope, taking into account the ship type, its equipment and outfitting. PRS may extend the scope of classification documentation, specified below if it is considered necessary upon examination of the ship technical specification and general arrangement plan.

.1 Data on the longitudinal, zone and local strength:
- basic theoretical data: body lines, hydrostatic curves,
- mass of light ship and its longitudinal distribution,
- intended load conditions and mass distribution of cargo and provisions,
- deck vehicles distribution plan and maximum load per vehicle axis,
- calculation of maximum still water bending moments and shear forces,
- minimum and maximum draught of 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 liquid cargo intended to be carried in tanks,
- heights of air pipes, measured from the tank tops or from the decks above which these pipes are carried,
- mass of heavy machinery components,
- other local loads or forces which will affect the hull structure;
- description of the assumed changes of the ship ballasting on a voyage and the description of consequential limitations due to weather conditions.

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

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

.4 Shell expansion, including arrangement of primary supporting members, stiffeners, bulkheads, decks and platforms, as well as the arrangement and scantlings of shell openings; the extent of bottom flat portion of ship fore part shall be indicated in the drawing.

.5 Laminating plan for hull, decks and bulkheads.

.6 Laminating plan for other composite hull members, if not included in the drawings of these members.

.7 Drawings of decks and platforms, including the arrangement and dimensions of the openings.

.8 Drawing of the double bottom.

.9 Drawings of longitudinal and transverse bulkheads, as well as the tank bulkheads, including the height of tank overflow and air pipes.

.10 Drawings of machinery spaces, including foundations of main engines and boilers, as well as the bottom structure under the foundations, tanks, pillars, strengthenings, e.g. for upper fastening of the engine; type and rating of the engine shall be given, and the guidelines of the engine manufacturer concerning the foundation shall be taken into account; the height of tank overflow pipes and air pipes shall be specified.

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

.12 Drawings of forward portion and stem.

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

.14 Drawings of superstructures and deckhouses.

.15 Drawings of mast supports.

.16 Technological documentation – the description of construction procedure.

.17 Liquid tanks' painting plan.

.18 Calculations of hull, decks, bulkheads structures acc. to PRS *Rules*.

.19 Calculations of hull and deck strengthenings in way of machinery and equipment heavily loading the structures.

.20 Drawings of foundations of machinery heavily loading the structures and of their fixing (laminating) to the hull.

.21 Specification of applied binders, reinforcements and cores.

9.1.3 Workshop documentation of ship

Upon approval of classification documentation by the PRS Head Office, the following workshop documentation shall be submitted for consideration and agreement:
- plan of hull and tanks tightness tests;

– drawings showing passage of pipelines, ventilation ducts and cables through the hull plating, bottom, decks, bulkheads, primary supporting members, etc.;
– drawings of local strengthenings under gear and machinery not shown in classification documentation;
– programme of mooring and sea trials.

9.1.4 Tests of Glass-reinforced Hull Structures

.1 Forepeak bulkhead shall be subjected to a tightness test with the test pressure of the water head equal to the upper edge of the forepeak tank. Hydraulic test may be replaced by a pneumatic test using a pressure not less than 15 kPa, provided that the forepeak walls (including upper wall) were verified by calculation for 15 kPa pressure.
.2 Machinery space bulkheads shall be subjected to a hose test with the pressure of 200 kPa or a pneumatic test using a pressure not less than 15 kPa, provided that the walls (including upper wall) were verified by calculation for 15 kPa pressure.
.3 Tanks shall be subjected to the hydraulic test by flooding them up to the top edge of the vent pipe or to the height equal to 2/3 of the distance between the tank top plating and the main deck or the tanks shall be subjected to a pneumatic test using a pressure not less than 15 kPa.
.4 Hull equipment, such as doors, windows, scuttles, etc. as well as means of closing of openings shall be subjected to tests like in the case of metallic hulls (see *Publication No. 21/P – Testing of the Hull Structures*).

The test methods are given in the *PRS Publication No. 21/P – Testing of the Hull Structures*.

9.2 Structural arrangement

9.2.1 General

9.2.1.1 Adopted design dimensions of hull members shall be verified for conformity with strength, rigidity and stability criteria specified in subchapter 9.4.

The verification requirements are referenced in 9.2, where requirements for particular structure members are specified.

9.2.1.2 In addition to the requirements for strength, rigidity and stability contained in subchapter 9.4, monolithic laminate structures, shall also comply with the requirements for minimum thickness and structural arrangements given in subchapter 9.2 for particular structure members.

9.2.1.3 In addition to the requirements contained in subchapter 9.4, sandwich structures shall also comply with the requirements for structural arrangements given in subchapter 9.2 for particular structure members, and the below requirements for minimum reinforcement content in sandwich coatings:
– bottom and sides plating and the inner bottom plating, external linings, liquid-tight surfaces of tanks: glass reinforcement – 3600 g/m^2, aramid and carbon reinforcement – 2700 g/m^2;
– bottom and sides plating and the inner bottom plating, internal linings: glass reinforcement – 2800 g/m^2, aramid and carbon reinforcement – 2000 g/m^2;
– protection strength deck plating and cargo deck plating, external linings: glass reinforcement – 2400 g/m^2, aramid and carbon reinforcement – 1900 g/m^2;
– protection strength deck plating and cargo deck plating, internal linings: glass reinforcement – 1600 g/m^2, aramid and carbon reinforcement – 1300 g/m^2;
– watertight bulkheads (not tank walls): glass reinforcement – 1600 g/m^2, aramid and carbon reinforcement – 1300 g/m^2;
– other decks (inside hull and superstructures): glass reinforcement – 1600 g/m^2, aramid and carbon reinforcement – 1300 g/m^2;
– deckhouse external walls: glass reinforcement – 1600 g/m^2, aramid and carbon reinforcement – 1300 g/m^2;
– other structure members: glass reinforcement – 1600 g/m^2, aramid and carbon reinforcement – 1300 g/m^2.

9.2.1.4 In agreement with PRS, in the structure of units of length *L* not exceeding 24 m, an integral system of stiffenings may be applied achieved by cladding with laminate of a grid made of structural foam or laminated in the mould.

The applied structure shall comply with the following requirements:
- the requirements of 9.4;
- the requirements of 9.2, including specification of used system;
- longitudinal stiffeners loaded with general hull bending shall be continuous;
- laminatings or flanges of stiffeneres glued to the plating shall transfer existing shear forces with maximum level of shear forces equal to 33% of the joint shear strength;
- in way of crossing of stiffeners of the same height, at least one of them shall have continuous web (webs for trapezoid stiffeners) and face plate;
- strength calculations of the applied material shall be submitted to PRS.

9.2.2 Botton and side plating

9.2.2.1 Keel

9.2.2.1.1 Flat keel breadth shall not be less than 0.1B. Flat keel thickness shall not be less than:

$$t_1 = 1.5t \quad [\text{mm}] \qquad (9.2.2.1.1)$$

t – the thickness of bottom plating complying with the strength requirements of 9.4 and with the minimum thickness criterion in 9.2.2.5.

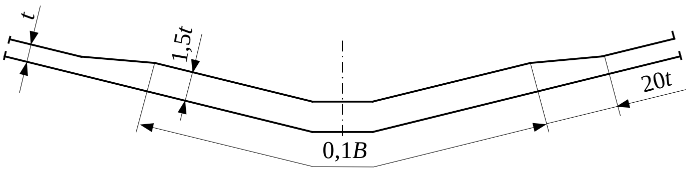


Fig. 9.2.2.1.1. Keel dimensions

9.2.2.1.2 The thickness of flat keel in hulls with technological division along the centre plane CP may not be less than:

$$t_1 = 2t \quad [\text{mm}] \qquad (9.2.2.1.2)$$

t – the thickness of bottom plating complying with the strength requirements of 9.4 and with minimum thickness criterion of 9.2.2.5

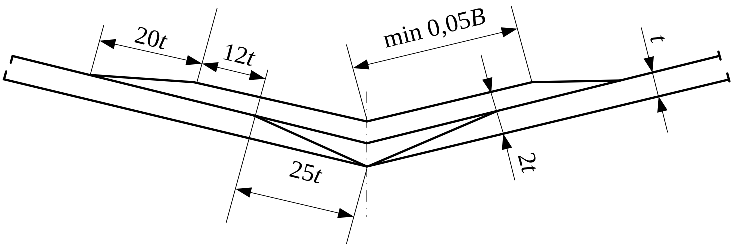


Fig. 9.2.2.1.2. Dimensions and structure of keel with technological division along CP

9.2.2.1.3 If the bottom plating has sandwich structure, the keel shall have monolithic structure over the bottom breadth defined in 9.2.2.1.1, in accordance with Fig. 9.2.2.1.3.

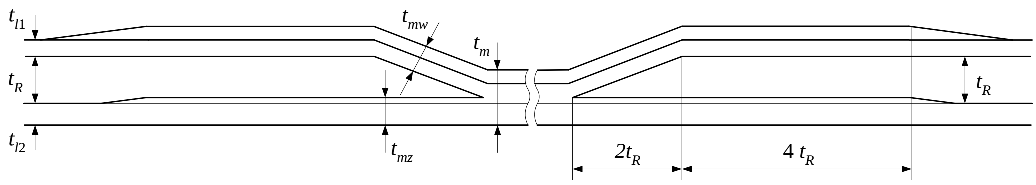


Fig. 9.2.2.1.3

t_{l1}, t_{l2} – the thickness of the bottom sandwich structure linings, [mm];
t_R – the core thickness, [mm];

t_m – the thickness of the keel monolithic laminate, [mm];
t_{mz} – the thickness of external lining in region adjacent to keel, [mm];
t_{mw} – the thickness of internal lining in region adjacent to keel, [mm].

It is recommended to calculate the values of t_{mz} and t_{mw} from the formulae:

$$t_{mz} = 0.4 \cdot t_m \quad \text{[mm]} \qquad (9.2.2.1.3\text{-}1)$$

$$t_{mw} = 0.6\, t_m \quad \text{[mm]} \qquad (9.2.2.1.3\text{-}2)$$

The thickness of monolithic laminate of keel t_m may be calculated from the below formula, unless the keel transfers additional local loads:

$$t_m = k \cdot 2.4 \sqrt{t_R \cdot t_l} \quad \text{[mm]} \qquad (9.2.2.1.3\text{-}3)$$

where:
$t_l = \min(t_{l1}, t_{l2})$, [mm];
k = 1.5 – coefficient of increasing the keel thickness in relation to bottom thickness.

9.2.2.1.4 Increase of the thickness of box keel of the vertical aft blade or of sternframe and the increase width shall not be less than the values defined below (see Fig. 9.2.2.1.4).

The dimension e shall not be less than 0.25h and not less than 50 mm.

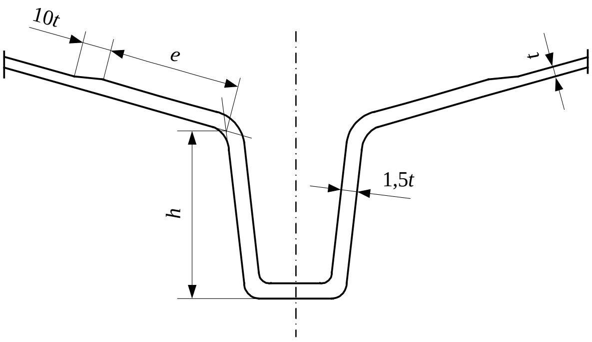


Fig. 9.2.2.1.4. Box keel

9.2.2.2 Bilge, transom, bilge keel, local plating reinforcements

9.2.2.2.1 The thickness of bent bilge and transom shall be increased by 50% over the width defined in Fig. 9.2.2.1.1.

The dimension e shall not be less than 0.025B and not less than 50 mm, t – bottom plating thickness [mm].

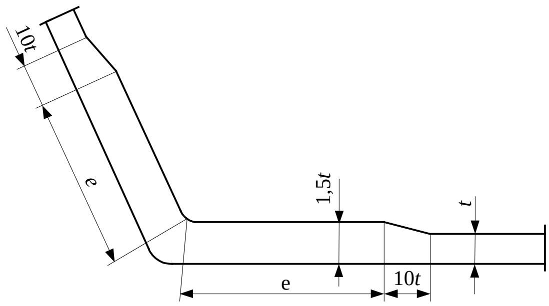


Fig. 9.2.2.2.1. Thickness of bilge or transom

9.2.2.2.2 For sandwich structure of bottom and sides, it is recommended to make a bent bilge as a monolithic structure. The thickness of such bilge shall be not less than 1.5 t, where t – the plating thickness required for monolithic bottom.

9.2.2.2.3 Structural arrangements of bilge keel which require drilling the plating are not allowed. Repeated laminating of keel (using laminate or plastic foam moulds) or laminating the keel directly in the hull mould are permitted. Fig. 9.2.2.2.3 shows an example solution.

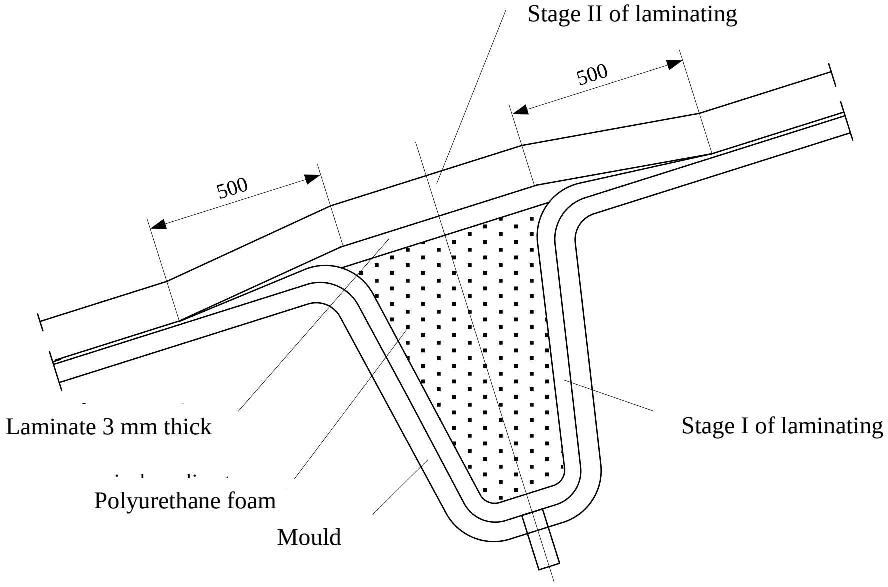


Fig. 9.2.2.2.3. Example of proper construction of bilge keel

9.2.2.2.4 In the region of penetration of propeller tube, rudder trunk and in region of fixing propeller shaft brackets, the thickness of monolithic hull and deck plating shall be increased by at least 50% compared to adjacent plating.

9.2.2.3 Stem, sternframe, rudder post

The stem width shall not be less than the keel width, and at deck not less than 60% of keel width.

The stem thickness may be reduced from the keel thickness up to the value of t_{dz} at deck:

$$t_{dz} = \frac{t_s + t_b}{2} \qquad (9.2.2.3)$$

t_s – keel thickness, [mm];

t_b – side thickness, [mm].

In the case of sandwich structure of the side, the stem along the above specified width shall transfer into the monolithic structure or a protective structure of bow shall be applied (see Fig. 9.2.2.3).

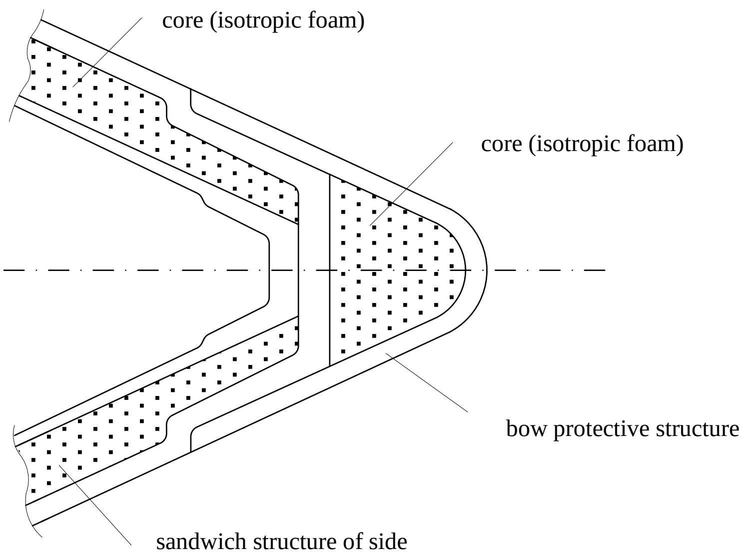


Fig. 9.2.2.3. Ship stem structure with sandwich sides

The structure, dimensions and fixing of sternframe/ruder post made of polymer composites will be separately considered by PRS.

9.2.2.4 Sheer strake

9.2.2.4.1 The sheer strake shall be considered as side plating locally reinforced in way of side – deck connection and in way of fender. The thickness of monolithic plating in way of reinforcement shall not be less than 1.5*t*, *t* being the thickness of monolithic laminate side plating. For sandwich side plating in way of connection with deck, the sheer strake shall be executed as a monolithic structure and increasing sheer strake thickness shall be considered as necessary. An example of sandwich side connection with deck is shown on Fig. 9.2.10.3c.

9.2.2.5 Bottom and sides

9.2.2.5.1 Internal forces and stresses in bent plates shall be determined according to the requirements given in 9.4.3.10. The loads shall be taken in accordance with 9.3. Plating plates (both monolithic and sandwich ones) shall comply with rigidity criteria specified in 9.4.3.12.2, strength criterion defined in 9.4.3.12.3 and 9.4.3.12.4, as well as buckling criterion given in 9.4.4.3.4 and 9.4.4.3.5.

9.2.2.5.2 The minimum thickness of monolithic laminate shall be not less than 5 mm.

9.2.2.5.3 If the sandwich structure of side is exposed to impact or increased wear, then the thickness of external lining shall be increased by at least 50%.

9.2.2.5.4 The reinforcement mass of the kingston box installed in the bottom shall be not less than bottom plating.

9.2.2.5.5 Any openings in the plating shall have rounded corners, and openings of diameter $d \geq 150$ mm shall be compensated by doubling thickness of laminate plating within the area specified acc. to Fig. 9.2.2.5.5.

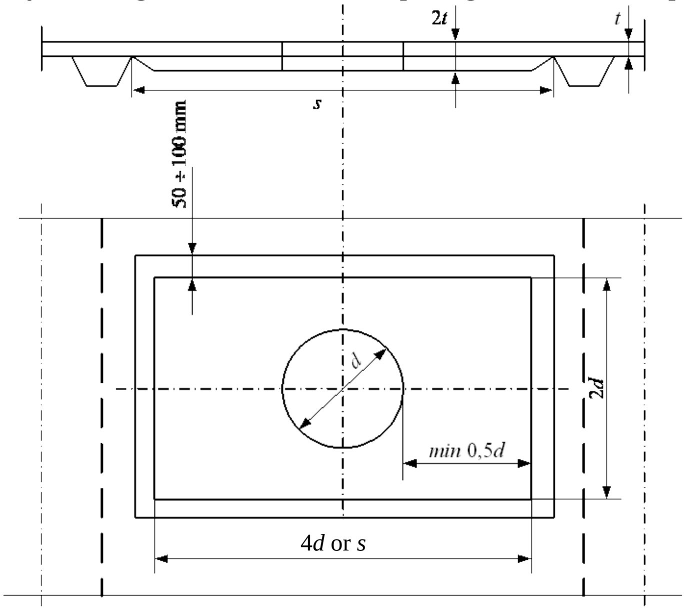


Fig. 9.2.2.5.5. Compensation of openings in plating

The distance from the top edge of side opening to the nearest above deck shall be at least two opening diameters.

Big openings in sides or bulwark shall be located as far away from the deck steps.

9.2.2.5.6 Flow openings in primary structure members and stiffeners

The flow openings shall be so designed to ensure appropriate flow area and to avoid at once stresses concentration at the opening.

Openings in trapesoid profiles shall be formed with the use of profiles. The opening edges shall be properly tighten. The opening height shall not exceed 1/3 of the stiffener height.

9.2.3 Single bottom

9.2.3.1 Each ship shall have the bottom centre girder. Side girders shall also be used if the distance between the longitudinal and side exceeds 2.5 m.

The spacing of girders shall not exceed 2.5 m. They shall be carried as far as possible towards the stem and stern.

Internal forces, stresses and strains shall be determined according to requirements of 9.4.7.

Loads shall be determined acc. to 9.3.

The bottom longitudinals shall comply with the rigidity and strength criteria specified in 9.4.7.5 and buckling criteria of 9.4.8.

9.2.3.2 The longitudinal bottom stiffeners shall be supported by floors, bulkheads or other primary structure members spaced not more than 2.0 m.

The longitudinal bottom stiffeners shall maintain their continuity when penetrating supporting structures.

In way of watertight bulkheads of tank walls, the structure continuity may be ensured by bracket end connections, provided appropriate strength of the connection is ensured.

External forces, stresses and strains in bottom stiffeners shall be determined according to requirements of 9.4.5. Stresses are adopted acc. to requirements of 9.3.

Longitudinal stiffeners shall comply with the rigidity, strength and stability criteria specified in 9.4.5.9 and 9.4.6.

9.2.3.3 Within transverse system of bottom structure, floors shall be used on each frame.

Within longitudinal system of bottom structure, the distance between floors or between transverse bulkheads and adjacent floors shall not be more than 2 m.

Within hull centre plane, the height of floors shall be not less than:

$$h = 0.00522B \text{ [m]} \tag{9.2.3.3}$$

Full floors shall generally be continuous from the bottom centre girder to the margin plate.

If at the dimensioning of bottom longitudinals, their span has been assumed as equal to the transverse bukheads/divisions spacing, then spacing of adjacent longitudinals or longitudinal bulkheads may be taken as the floor span. Otherwise spacing of face plates of both sides frames (or of longitudinal bulkheads) shall be taken as the floor span or MES calculations shall be performed, see 9.4.7.3.

Using initially assumed structural dimensions of floors, internal forces, stresses and deformations shall be determined in accordance with requirements of 9.4.5 (for floors shaped as beam of defined support conditions) or of 9.4.7 (other cases).

Loads shall be assumed acc. to 9.3.

Floors shall comply with rigidity, strength and stability criteria, according the requirements of 9.4.7 and 9.4.8 (other cases).

9.2.4 Double bottom

9.2.4.1 The bottom centre girder shall be applied in the ship centre plane.

The height of the bottom centre girder shall be not less than 650 mm and be sufficient to ensure access to all bottom parts.

If the bottom centre girder is spaced of the side by more than 3 m, the bottom side girders shall be applied. Spacing of side girders shall be not more than 3 m. The girders shall be carried as far as possible towards stem and stern.

9.2.4.2 The bottom and internal bottom longitudinal stiffeners shall be supported with plate floors and bracket plates. The longitudinal stiffeners shall maintain their continuity when penetrating the supporting structure. Plate floors may have a monolithic or sandwich structure. Stiffeners with void or non-structural cores may be used as floors.

The plate floors may not be spaced by more than 2.0 m.

9.2.4.3 Within transverse system of framing, open floors shall be fitted between plate floors.

Supporting plates in open floors shall be of the same thickness as plate floors (if they are monolithic), and the unsupported span shall be stiffened.

The width of supporting plates connecting bottom frames and inner bottom frames with the bottom centre girder and with margin plate shall be not less than 0.75 the thickness of the bottom centre girder. Where vertical connections are used, they shall not be considered an effective support of inner and outer bottom frames.

9.2.4.4 For longitudinal system of framing, the supporting plates shall extend from the centre girder and margin plate to the nearest longitudinal stiffening. However, the width of such plate may not be less than 0.75 the height of the bottom centre girder. The supporting plates shall be applied on each web frame at margin plate and at the bottom centre girder, side girders with spacing not more than 1.0 m. The supporting plates at side girder shall be used if it is necessary to fulfil the strength and rigidity criteria.

9.2.4.5 The thickness of a plate (monolithic) floor shall be not less than 5 mm.

9.2.4.6 Plate floors shall in general be continuous from the bottom centre girder to margin plate.

9.2.4.7 Within the bottom girder and floor system, the internal forces, stresses and deformations shall be determined for assumed design dimensions, according to requirements of 9.4.7.

Loads shall be assumed according to 9.3.

Girders and floors shall comply with rigidity and strength criteria acc. to 9.4.7.5 and buckling criteria acc. to 9.4.8.

9.2.4.8 Internal forces, stresses and deformations in transverse frames, inner bottom frames and bottom and inner bottom longitudinal stiffeners shall be determined considering requirements of 9.4.5.

Loads shall be assumed in accordance with 9.3.

The stiffeners shall comply with strength, rigidity and stability criteria specified in 9.4.5.9 and 9.4.6.

9.2.5 Side framing

9.2.5.1 The side frames shall be continuous between floors and decks. Their ends shall be adequately stiff as regards rotation.

9.2.5.2 The longitudinal side stiffeners shall be supported on transverse bulkheads, web frames or other structure elements located at a distance not more than 2.0 m.

The longitudinal side stiffeners shall maintain their continuity when penetrating the supporting structures. In way of bulkheads or tank walls, the structural continuity may be ensured using bracket connections.

9.2.5.3 The internal forces, stresses and deformations in transverse side frames and longitudinal side stiffeners shall be determined in accordance with 9.4.5.

Loads shall be assumed according to 9.3.

The transverse side frames and longitudinal side stiffeners shall comply with the strength and rigidity criteria of 9.4.5.9 and buckling criteria of 9.4.6.

9.2.5.4 The web frames supporting longitudinal side stiffeners shall be effectively connected with a plate floor and transverse primary supporting member. Stresses and strains may be calculated with the use of flat frame model, which includes the web frame, plate floor and transverse primary supporting member, in accordance with 9.4.7.

The rigidity and strength criteria specified in 9.4.7.5 and buckling criteria specified in 9.4.8 shall be complied with.

9.2.5.5 Side stringer shall be supported by web frames, bulkheads or other primary structure members, spaced by not more than 6.0 m. The side stringer shall maintain its continuity when passing transverse bulkheads. In way of penetration through tank walls, the member continuity may be ensured by bracket connections, provided it is justified by relevant strength of the connection.

9.2.5.6 The internal forces, stresses and deformations in the side stringer system shall be determined for the assumed structural dimensions, in accordance with the requirements of 9.4.7 and using mechanical methods or MES calculations.

Loads shall be assumed according to 9.3.

The members shall comply with rigidity and strength criteria specified in 9.4.7.5 and buckling criteria specified in 9.4.8.

9.2.6 Bulkheads and deep tanks

9.2.6.1 The watertight bulkheads and collision bulkheads shall be arranged in accordance with the requirements of, respectively, *SOLAS II-1*, Part B-2 or *European Commission Directive 2009/45/EC*.

The forepeak bulkhead or collision bulkhead shall be watertight up to the bulkhead deck.

The forepeak bulkhead shall be extended to the bulkhead deck.

9.2.6.2 The minimum thickness of watertight bulkhead made of monolithic laminate may not be less than 3.5 mm, and in the case of deep tank bulkhead the thickness may not be less than 4.5 mm.

9.2.6.3 If he bulkheads are made of steel or aluminium alloys, their dimensions and structure shall comply with the requirements of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull*. The method of connection with hull structure is subject to separate consideration by PRS.

9.2.6.4 Hull tanks shall not have sandwich structure.

It is recommended to use fuel tanks as independent tanks.

Laminate tanks shall not be used for liquids of flash point equal to 55°C or lower.

9.2.6.5 If a deep tank extends from one side to the other, a full bulkhead or a wash bulkhead shall be applied in the centre plane.

9.2.6.6 If structural members (such as longitudinal bottom stiffeners) penetrate the plating of watertight bulkhead or tank, and any leak to adjacent space can be dangerous or undesirable, a small cofferdam of min. 10 mm in length (5 mm on both sides of the wall) shall be made in the core of the trapezoid profile, e.g. by filling the foam void with epoxy resin.

9.2.6.7 A tank structure with stiffeners inside the tank shall be avoided.

9.2.6.8 The structure of tank walls shall be designed for pressure equal to at least 15 kPa.

9.2.6.9 Internal forces, stresses and deflections of bent plates shall be determined in accordance with requirements given in 9.4.3.10, 9.4.3.11 using assumed dimensions of bulkhead/tank plating. Loads shall be assumed according to 9.3. Plating (both monolithic and sandwich) shall comply with the rigidity criteria specified in 9.4.3.12.2, strength criteria defined in 9.4.3.12.3 and 9.4.3.12.4 and buckling criterion specified in 9.4.4.

9.2.6.10 Internal forces, stresses and deformations in bulkhead/tank wall stiffeners shall be determined for assumed design dimensions, taking into account the requirements of 9.4.5.

Loads shall be assumed in accordance with 9.3.

Stiffeners shall comply with strength and rigidity criteria given in 9.4.5.9 and stability criteria of 9.4.6.

9.2.6.11 Internal forces, stresses and deformations in bulkhead/tank wall primary supporting members shall be determined for assumed design dimension, according to the requirements of 9.4.7.

Loads shall be assumed in accordance with 9.3.

The primary supporting members shall comply with rigidity and strength criteria specified in 9.4.7.5 and stability criteria of 9.4.8.

9.2.6.12 Internal surfaces of tanks shall be protected by a coating system against liquid penetration into the tank plating.

9.2.6.13 Cofferdams shall be used between fresh water tanks and fuel oil tanks or sanitary water tanks.

9.2.7 Deck structure

9.2.7.1 Deck plating may be made as monolithic laminate or sandwich structure. The plating may be stiffened by (transverse) deck beams supported by longitudinals or longitudinal stiffeners supported by deck transverse girders.

9.2.7.2 Within the transverse system of framing, the deck beams shall be applied on each frame. The deck transverse girders used in the longitudinal framing system shall be effectively connected to the side web frames.

9.2.7.3 The primary supporting members shall maintain continuity when penetrating bulkheads.

9.2.7.4 The deck structure subjected to concentrated loads shall be respectively strengthened.
In the case of vehicle decks, the method of calculation of local strength shall be agreed with PRS. Loads shall be assumed in accordance with 9.3.

9.2.7.5 The minimum thickness of strength, cargo and weather deck made of monolithic laminate may not be less than 4 mm, the minimum thickness of decks inside the hull and superstructures which are not a strength nor cargo deck, may not be less than 3 mm.

9.2.7.6 For deep transverse primary supporting member and deck stringers, tripping brackets shall be used.

9.2.7.7 Internal forces and stresses in bent plates shall be determined according to requirements of 9.4.3.10, 9.4.3.11 using assumed dimensions of deck plating. Loads shall be assumed in accordance with 9.3. Plating (both monolithic and sandwich) shall comply with rigidity criteria given in 9.4.3.12.2, strength criteria defined in 9.4.3.12.3 and 9.4.3.12.4, as well as stability criteria specified in 9.4.4.

9.2.7.8 Internal forces, stresses and deformations in longitudinal stiffeners/deck beams shall be determined for the assumed design dimensions, considering the requirements of Chapter 9.4.5.
Loads shall be assumed in accordance with 9.3.
Stiffeners shall comply with the strength and rigidity criteria given in 9.4.5.9 and buckling criteria specified in 9.4.6.

9.2.7.9 Internal forces, stresses and deformations in deck primary supporting members shall be determined for the assumed design dimensions, according to the requirements of 9.4.7.
Loads shall be assumed in accordance with 9.3.
The primary supporting members shall comply with the strength and rigidity criteria given in 9.4.7.5 and buckling criteria specified in 9.4.8.

9.2.7.10 The openings in a deck shall have rounded corners or such of elliptical or parabolic shape.
The corner radius shall be not less than 0.10 of the opening width. Where rounded corners are used for large openings, e.g. loading hatches, the deck thickness in way of the corners shall be increased by 25%, in accordance with Fig. 9.2.7.10.

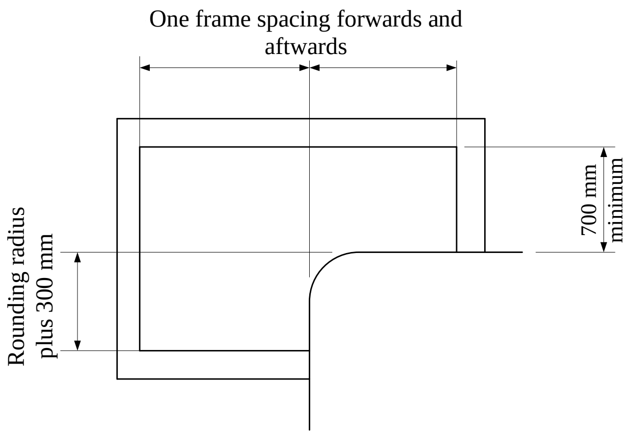


Fig. 9.2.7.10

For elliptical or parabolic corners, the proportion of the corner bigger length to smaller length shall be 2:1, whereas the smaller length shall be not less than 0.05 of the opening width and not less than 300 mm; increasing deck thickness in way of corners is not required.

The stiffeners ended on the opening shall be connected with the opening coamings and the primary supporting members transferring loads from the coaming to hull structure shall be adequately strengthened.

9.2.8 Superstructures

9.2.8.1 The requirements of this Chapter relate to superstructures and to deckhouses.

9.2.8.2 The plating thicknesses of superstructure end walls and decks made of monolithic laminate may not be less than the below values:

– fore walls – 3 mm;
– side walls – 2.5 mm;
– after walls – 2.5 mm;
– decks – 2.5 mm.

9.2.8.3 Longitudinal and transverse stiffeners of superstructure walls and decks shall maintain their continuity when penetrating supporting structures.

9.2.8.4 The deck longitudinals and longitudinal stiffeners shall be adequately supported by the primary supporting member system.

The unsupported length of the deck longitudinal or stiffener shall not be more than 2.5 m.

9.2.8.5 Plating and supporting structure in way of openings, masts, cranes, machinery and equipment and structures subject to vibration loads shall be properly strengthened.

9.2.8.6 Superstructure end walls shall be effectively supported in the form of bulkheads, divisions, frames or pillars.

In way of superstructure end connection with the side, the side plating thickness shall be additionally increased.

9.2.8.7 Internal forces and stresses in bent plates shall be determined in accordance with the requirements given in 9.4.3.10, 9.4.3.11 using assumed dimension of bulkhead/tanks plating. Loads shall be assumed in accordance with 9.3. Plating (both monolithic and sandwich) shall comply with rigidity criteria given in 9.4.3.12.2, strength criteria defined in 9.4.3.12.3 and 9.4.3.12.4, as well as buckling criteria specified in 9.4.4.

9.2.8.8 Internal forces, stresses and deformations in the wall and deck stiffeners shall be determined for the assumed design dimensions, considering the requirements of Chapter 9.4.5.

Loads shall be assumed in accordance with 9.3.

Stiffeners shall comply with the strength and rigidity criteria specified in 9.4.5.9 and buckling criteria given in 9.4.6.

9.2.8.9 Internal forces, stresses and deformations in wall and deck primary supporting members shall be determined for the assumed design dimensions, according to the requirements of 9.4.7.

Loads shall be assumed in accordance with 9.3.

The primary supporting members shall comply with the strength and rigidity criteria defined in 9.4.7.5 and buckling criteria of 9.4.8.

9.2.9 Seatings, pillars

9.2.9.1 Seatings

Engines and other machinery shall be placed on strong longitudinals, which are adequately supported and stiffened.

Longitudinals shall be attached to the structure members of bottom, sides and decks and this structure shall ensure transfer of forces acting longitudinally and transversely.

An example arrangement of the engine seating is shown in Fig. 9.2.9.1-1.

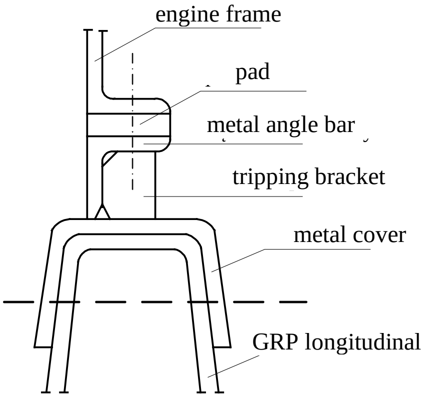


Fig. 9.2.9.1-1

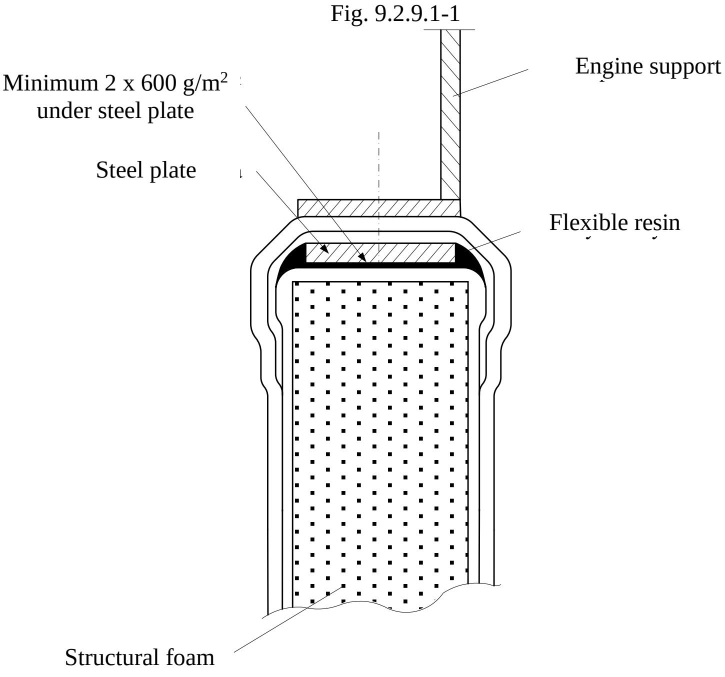


Fig. 9.2.9.1-2

9.2.9.2 Pillars

Pillars shall be made of steel or aluminium alloys. Structures under pillars shall have adequate strength for relevant distribution of loads.

Pillar axes in tweendecks and holds shall in general be vertically aligned.

Except pillars supporting the deck primary supporting members, additional pillars may be required under deckhouses, anchoring equipment, cargo winches and in other places.

Calculations of metal pillars shall be performed according to the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull*.

Vertical bulkhead stiffeners, supporting deck primary supporting members, shall comply with the requirements for pillars.

The rated axial force *P* acting in vertical stiffener of the bulkhead supporting deck primary members shall be calculated from the below formula:

$$P = sbp + P_P \quad \text{[kN]} \qquad (9.2.9.2\text{-}1)$$

P_p – load from above located pillar, [kN];
b – average width/length of the deck part supported on vertical stiffener of supporting bulkhead, [m];
s – spacing of vertical stiffeners of supporting bulkhead, [m];
p – design pressure acting on the supported deck, [kPa].

$$P < \frac{P_E}{3} \qquad (9.2.9.2\text{-}1)$$

where:
P_E – critical values of compressive force, acc. to 9.4.8.2, [kN].

9.2.10 Joints of hull structure member

9.2.10.1 General

Specified in subchapter 9.2.10 connection arrangements shall be treated as recommended. Application of other arrangements requires previous agreement with PRS.

9.2.10.2 Butt joints

9.2.10.2.1 Where butt joints are used, step by step chamfered butt joints have better strength properties (Fig. 9.2.10.2.1).

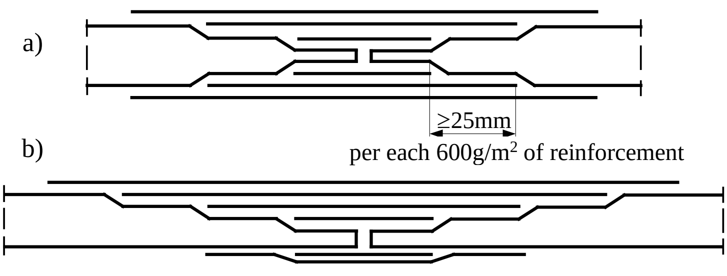


Fig. 9.2.10.2.1. Butt joints with chamfering

9.2.10.2.2 Less loaded elements and elements of small thickness can be joined without chamfering (Fig. 9.2.10.2.2).

Number of layers of the joining laminate shall be not less than the number of layers of thinner of the joined elements.

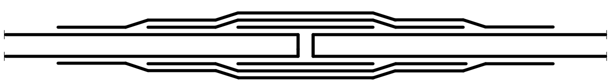


Fig. 9.2.10.2.2. Butt joints without chamfering

9.2.10.2.3 Recommended method of joining hull plating in the plane transverse to hull axis is shown in Fig. 9.2.10.2.3.

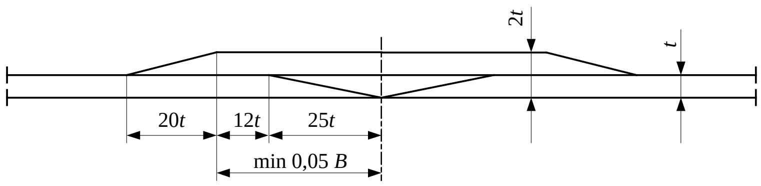


Fig. 9.2.10.2.3. Recommended method of joining hull plating in transverse plane

9.2.10.3 Joints deck – side

Joints of deck with side shall be executed as lap joints or laminated doubling joints.
Examples of deck – side joints are shown in Fig. 9.2.10.3.
In heavy sailing or mooring conditions, the deck– side joints may be executed with use of screws.
Spacing of screws, when used, shall be not more than $20d_s$, where d_s – the screw diameter.
The screw diameter may not be less than the thickness of the thinner connected element.

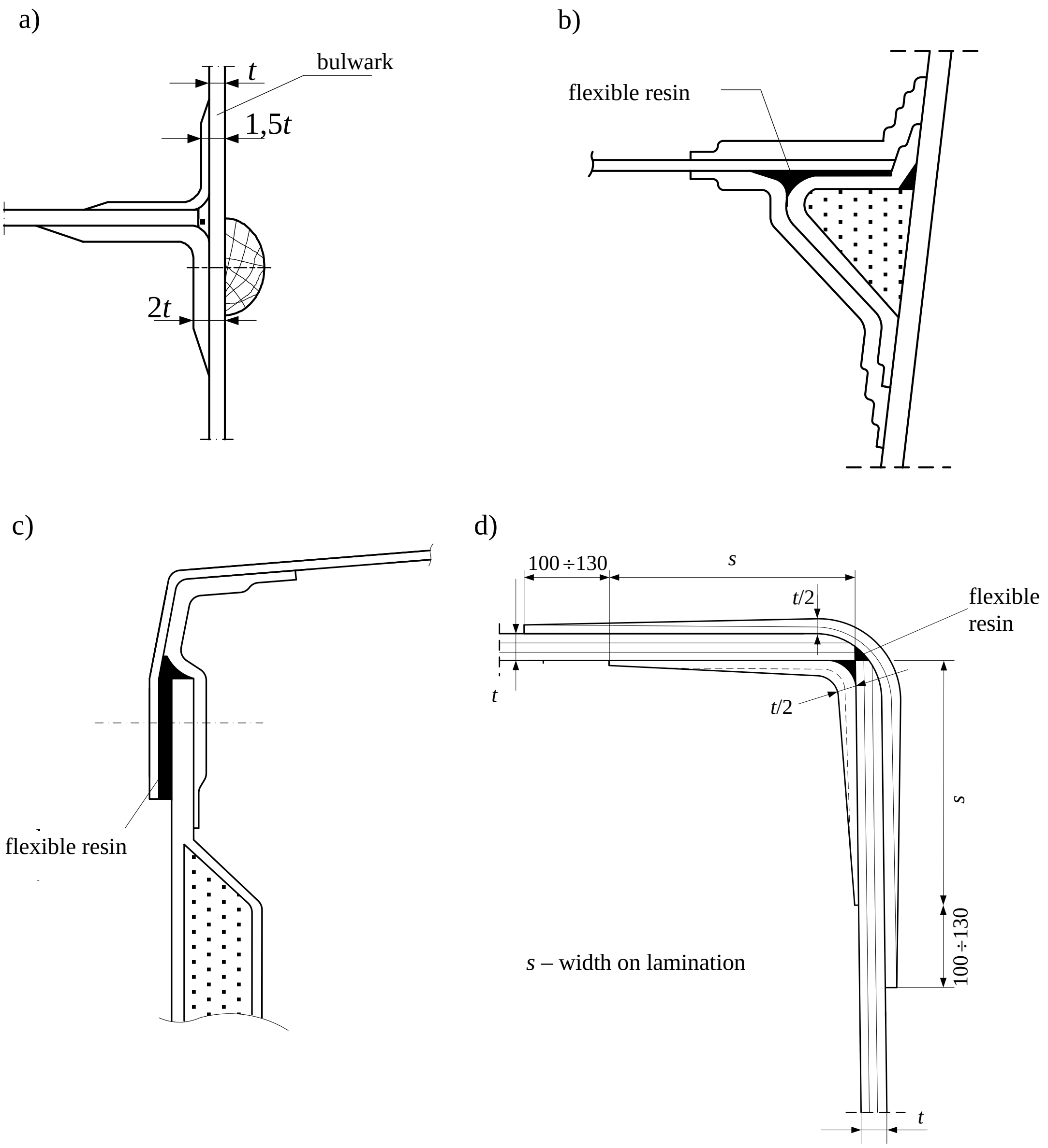


Fig. 9.2.10.3. Recommended arrangements of deck–side joint

9.2.10.4 Angular connections

9.2.10.4.1 Typical angular connection arrangement is shown in Fig. 9.2.10.4.1.

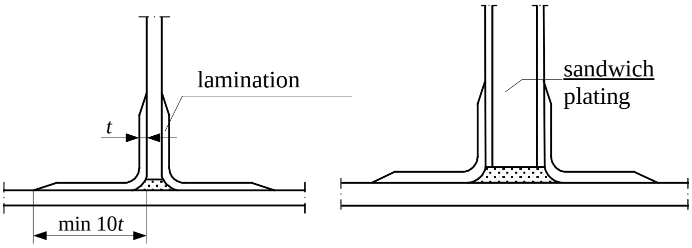


Fig. 9.2.10.4.1. Typical angular connections

The use of other types of angular connections is each time subject to separate consideration by PRS.

9.2.10.4.2 The weight of glass reinforcement of laminations on one side shall be not less than:
- 50% of the weight of thinner element reinforcement – for monolithic laminate elements,
- the weight of thinner lining reinforcement – for sandwich plating elements.

For single-side laminations, the given above values shall be doubled. The weight of glass reinforcement for laminations may not be less than 2500 g/m^2, and the weight of aramid or carbon reinforcement – not less than 1900 g/m^2.

9.2.10.5 Joints of bulkhead with hull plating and decks

Recommended joints of bulkhead with hull plating or decks are shown in Fig. 9.2.10.5.

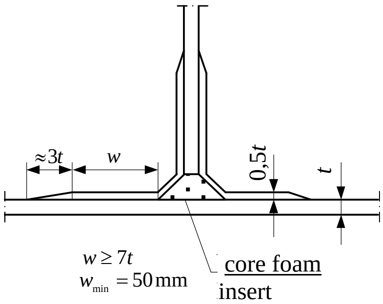


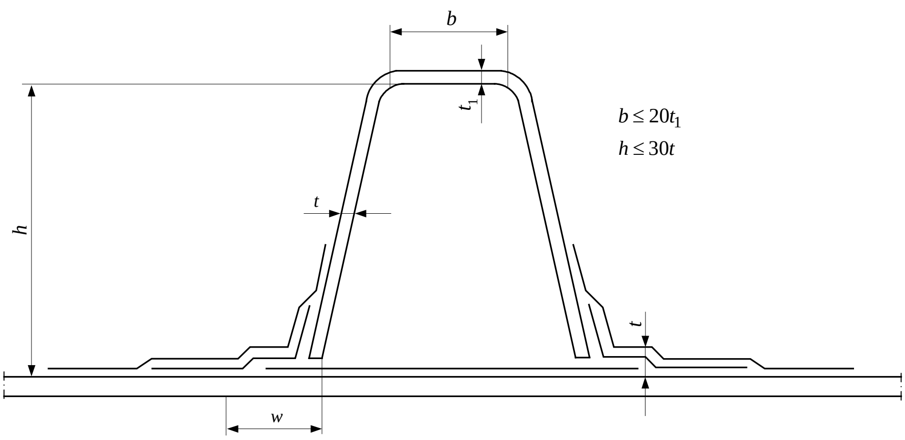
Fig. 9.2.10.5 Bulkhead joint with hull plating or decks

9.2.10.6 Attachment of stiffeners

9.2.10.6.1 It is recommended to perform stiffeners and primary supporting members with void cores or those made from non-structural materials as shown in Fig. 9.2.10.6.1.

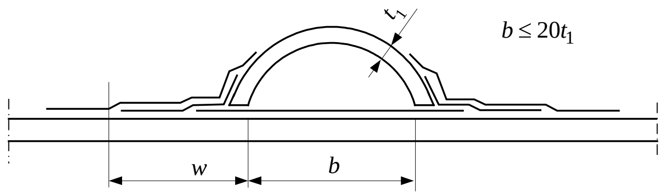
The Fig. 9.2.10.6.1 shows also required mutual dimensional proportions for stiffener elements or their minimum dimensions.

a)



$w = 0.2\,h$, however, not more than $6\,t$
$w_{min} = 50$ mm

b)



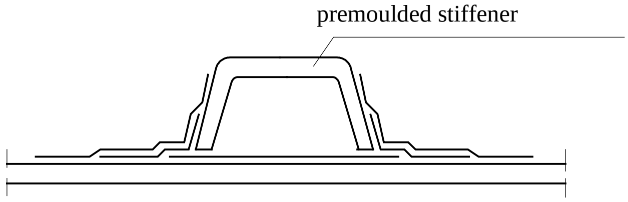
$w \approx 0.5\,b$, mm
$w_{min} = 50$ mm
$b \leq 20\,t_1$

Fig. 9.2.10.6.1. Stiffeners with void core or made from non-structural materials

The use of other types of stiffeners is each time subject to separate consideration by PRS.

9.2.10.6.2 Stiffeners made from laminate shapes may be joined with plating as shown in Fig. 9.2.10.6.2, and the dimensional proportions and the minimum dimensions shall comply with the requirements shown in Fig. 9.2.10.6.1.

a)



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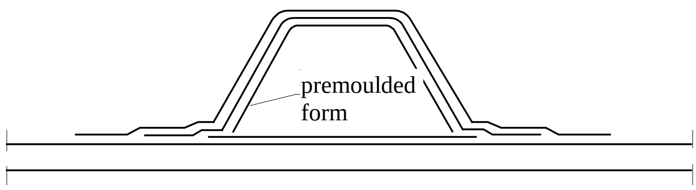


Fig. 9.2.10.6.2. Shape stiffeners

9.2.10.6.3 Where plywood bulkheads and divisions have been used in the grp laminate structure, they shall be joined with the plating by laminate angle bars with total reinforcement mass of:

2700 g/m^2 – for divisions thickness not exceeding 12 mm,
3600 g/m^2 – for division thickness above 12 mm, but not more than 20 mm,
4500 g/m^2 – for division thickness above 20 mm, but not more than 25 mm.

Where structural members of height $h > 30t$ are used (h, t – see Fig. 9.2.10.6.1 a), appropriate stiffening of webs is required.

9.2.10.6.4 Stiffeners penetrations in primary supporting members and bulkheads (Fig. 9.2.10.6.4) shall be continuous, with the exception of end bulkheads of tanks.

The recommended arrangement of longitudinal stiffener joint with bulkhead is shown in Fig. 9.2.10.6.4. The primary supporting members shall be connected with bulkheads similar to stiffeners.

The arrangement of stiffener penetrations in bulkheads shall be such that the bulkhead tightness is not reduced. It applies also to trapezoid stiffeners.

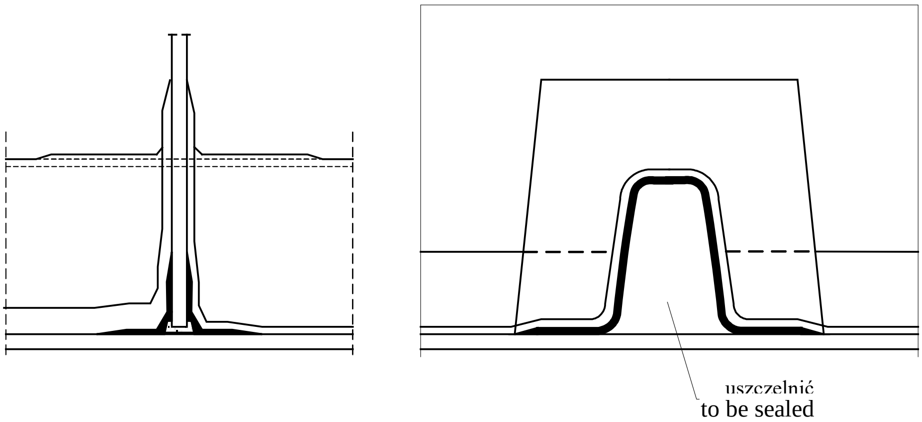


Fig. 9.2.10.6.4. Joint of longitudinal stiffener with bulkhead

9.2.10.7 Sandwich and monolithic plating

9.2.10.7.1 Plywood inserts shall be used instead of core foam or monolithic plating shall be provided inside sandwich plating (between linings) in the places of the equipment fastening. The recommended arrangement of connecting the sandwich plating with massive plating is shown in Fig. 9.2.10.7.1.

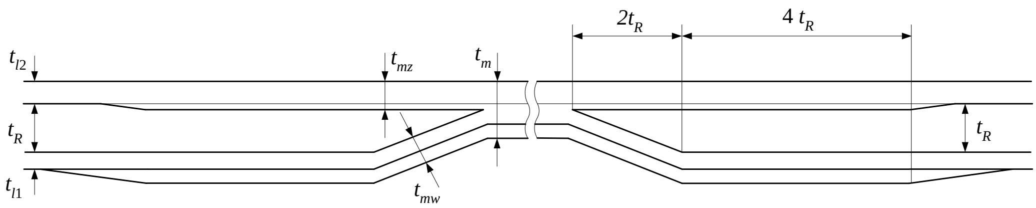


Fig. 9.2.10.7.1. Connection of sandwich plating with massive plating

t_{l1}, t_{l2} – thickness of the sandwich structure linings, [mm];
t_m – thickness of monolithic plating, [mm];
t_{mz} – thickness of external lining in the region adjacent to monolithic plating, [mm];
t_{mw} – thickness of internal lining in the region adjacent to monolithic plating, [mm];

It is recommended to calculate the values t_{mz} and t_{mw} from the below formulae

$$t_{mz} = 0.4\, t_m \text{ [mm]} \qquad (9.2.10.7.1\text{-}1)$$

$$t_{mw} = 0.6\, t_m \text{ [mm]} \qquad (9.2.10.7.1\text{-}2)$$

The thickness t_m and the range of monolithic laminate shall be chosen by appropriate calculations, respectively to the loads acting in the given place.

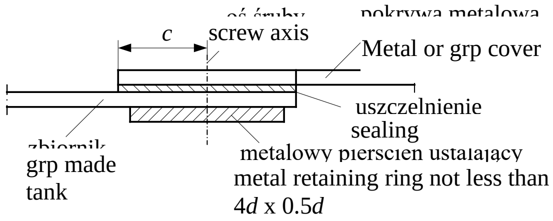
9.2.10.7.2 Core foam shall be chamfered with 1:2 slope in all passages from the sandwich plating into the monolithic one. (see Fig. 9.2.10.7.1).

9.2.10.8 Openings and edges

9.2.10.8.1 Any protruding laminating edges shall be sealed with resin.
The edges of sandwich plates and openings therein shall be sealed with mat and resin.

9.2.10.8.2 The recommended arrangements for mounting manholes to tanks are shown in Fig. 9.2.10.8.2.

a)



c = 3*d* –for grp made cover
c = 2*d* – for metal cover
d – screw diameter (not less than 6.5 mm)

b)

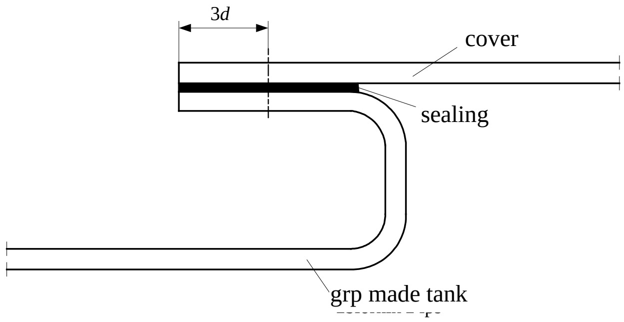


Fig. 9.2.10.8.2. Mounting manholes to tanks

9.3 Loads of structure

9.3.1 General

9.3.1.1 Application

9.3.1.1.1 The design load values determined in accordance with the provisions of this subchapter are applicable at dimensioning plating, plating stiffeners, ordinary structural members, complex structural member systems and supporting members, being elements of particular hull structures of ships of length $L \geq 24$ m. The values are taken as design loads, which can be used only within adopted system of requirements. For ships of length $L < 24$ m, the values of design loads shall be taken in accordance with the *Rules for the Classification and Construction of Small Sea-going Ships, Part II – Hull*.

9.3.1.1.2 The design compressive axial forces applied at dimensioning supporting members shall be determined in accordance with subchapter 9.3.5.

9.3.1.2 Component design loads

Static and dynamic components of loads due to below factors are considered at determining design loads of structure:

– sea pressure (see 9.3.2),
– pressure of liquids in tanks (see 9.3.3),
– pressure of dry cargo, stores and equipment (see 9.3.4).

9.3.1.3 General

9.3.1.3.1 Loads may be generally exerted from both sides on the plating under consideration and the structural members supporting such plating. The loads shall be determined independently and higher values shall be taken as design loads. In special cases, the design load can be taken as the difference between the loads imposed on both sides of the plating if both of them are imposed simultaneously.

Use of structures where pressure acting on plating separates it from laminated stiffeners is not recommended. In such cases, the stiffener–plating joint exposed to big pressures may require additional reinforcement and separate consideration by PRS.

9.3.1.3.2 Tanks for the carriage of oil shall be designed for liquid of density equal to that of sea water:

$$\rho = 1.025 \text{ t/m}^3 \qquad (9.3.1.3.2)$$

9.3.1.3.3 The structure of tanks for higher density liquids is subject to PRS consideration in each particular case. In such cases, the density applied as the basis for approval will be given in Appendix to the *Certificate of Class.*

9.3.1.3.4 For ships of restricted navigation area, pressure components or coefficients including dynamical part of local loads of structure may be reduced as follows:
– for area **II** – by 10%,
– for area **III** – by 30%,
– for passenger ships of Class C – by 40%,
– for passenger ships of Class D – by 50%.

Details are given at specific loads description. The above allowances apply in the case when no allowances given in 9.5.1.3 have been used in calculation of parameters of Chapter 9.5.

9.3.1.4 Symbols

b_a – the largest athwartship distance, parallel to *y* axis, from the load point to the tank corner at top of the tank most distant from the load point, [m];
b_s – breadth of tank top, [m];
b_z – distance, parallel to *y* axis, between tank sides or longitudinal wash bulkheads at the height of the load point in question, [m];
g – acceleration of gravity, [m/s^2] – may be taken 9.807 m/s^2;
h_a – vertical distance from the load point to the top of the tank or to the hatch coaming, [m]; for all high, narrow tanks, the value of h_a may be taken not greater than 15 times the smallest tank breadth (or length) measured above the load point;
h_g – vertical distance from the load point to the top of bulkhead, [m].
In ships with very large distance from the summer load waterline to the top of the bulkhead, h_g may be based on flooding calculation;
h_p – vertical distance from the load point to the top of air pipe, [m];
h_o – vertical distance from summer load waterline to the load point, [m];
h_z – height of tank, [m];
l_a – the largest longitudinal distance, parallel to *x* axis, from the load point to the tank corner at top of the tank most distant from the load point, [m];
l_s – tank top length, [m];
l_z – distance, parallel to *x* axis, between tight or wash transverse bulkheads at the height of the structural member in question, [m];
p_0 = 25 kPa;
p_v – safety valve opening pressure, [kPa];
T_m – minimum design draught, [m]; T_m shall be normally taken as 0.35*T*;
ρ – density of cargo, ballast or stores, [t/m^3];
P (x, y, z) – point for which the sea pressure is determined;
p_i – sea pressure in point *P*, i = 1, ... 5, [kPa].

9.3.2 Sea pressure

9.3.2.1 General

The external sea pressure acting on the ship's bottom, sides and the weather deck shall be determined in accordance with the formulae specified in 9.3.2.

9.3.2.2 External pressure acting on ship's hull

9.3.2.2.1 The external sea pressure acting at point P (x, y, z) of the ship's side below the summer load waterline or the bottom shall be determined in accordance with the following formula:

$$p_1 = 0.5\, p_{db} + 10(T - z) \quad \text{[kPa]} \qquad (9.3.2.2.1\text{-}1)$$

$$p_{db} = (1 + 0.036v)\left[0.7 Z_A + k_x \theta_A + 3|y|\Phi_A\right] + 0.02 L_0 \times \left[10 - 0.25\,(T - z)\right] \quad \text{[kPa]} \qquad (9.3.2.2.1\text{-}2)$$

$$k_x = \begin{cases} -4(x + 0.05 L_0) & \text{for} \quad x < -0{,}05 L_0 \\ 5{,}4(1 + 0.05 L_0) & \text{for} \quad x \geq -0{,}05 L_0 \end{cases} \qquad (9.3.2.2.1\text{-}3)$$

v – ship's speed, [knots];
Z_A, Θ_A, Φ_A – see 9.5.3.2 and 9.5.3.3;
x, y, z – co-ordinates of point $P(x, y, z)$ – see Fig. 9.5.2.1.

9.3.2.2.2 The external sea pressure acting at point P (x, y, z) of the ship's side at the level of the exposed deck shall be determined in accordance with the following formula:

$$p_2 = 0.5\, p_{ds} \quad \text{[kPa]} \qquad (9.3.2.2.2\text{-}1)$$

$$p_{ds} = \rho g\left[S_A - (z - T)\right] \quad \text{[kPa]} \qquad (9.3.2.2.2\text{-}2)$$

ρ = 1.025 t/m^3;
$[S_A - (z - T)] \geq 2$ shall be assumed;
S_A – see 9.5.3.7;
$z - T$ – distance from the summer load waterline to point P.

9.3.2.2.3 The pressure between the deck level and summer load waterline shall be determined by linear interpolation. The pressure in extreme points is determined in accordance with formulae 9.3.2.2.1-1 and 9.3.2.2.2-2.

9.3.2.2.4 The external sea pressure acting at point P (x, y, z) of the exposed deck shall be determined in accordance with the following formula:

$$p_3 = 0.5\, p_{dd} \quad \text{[kPa]} \qquad (9.3.2.2.4\text{-}1)$$

$$p_{dd} = \rho(g + 0.5\, a_v)\left[S_A - (z - T)\right] \quad \text{[kPa]} \qquad (9.3.2.2.4\text{-}2)$$

$[S_A - (z - T)] \geq 2$ shall be assumed;
S_A and a_v – see 9.5.3.7 and 9.5.4.1;
ρ = 1.025 t/m^3.

9.3.2.2.5 The sea pressure acting on the ship's bottom and sides which may be deducted from the internal pressure in tanks adjacent thereto corresponds to the minimum design draught of the ship T_m in still water. The value of the external pressure shall be determined in accordance with the following formula:

$$p = \rho g(T_m - z) \quad \text{[kPa]} \qquad (9.3.2.2.5)$$

$p \geq 0$ shall be taken;
ρ = 1.025 t/m^3;
z – co-ordinate of the considered point.

9.3.2.3 External pressure acting on superstructures

9.3.2.3.1 The external sea pressure acting on exposed walls of a superstructure, deckhouse or engine room casing may be determined in accordance with the formulae given in 9.3.2.3.2 and 9.3.2.3.3.

9.3.2.3.2 At point P (x, y, z) of the exposed front wall of superstructure or deckhouse:

$$p_4 = 3 p_{dd} \quad \text{[kPa]} \qquad (9.3.2.3.2)$$

$[S_A - (z - T)] \geq 1$ shall be assumed;
p_{dd} – see 9.3.2.2.4.

9.3.2.3.3 At point P (x, y, z) of exposed side and aft walls of superstructures and deckhouses:

$$p_5 = 0.5\, p_{ds} \text{ [kPa]} \tag{9.3.2.3.3}$$

$[S_A - (z - T)] \geq 1$ shall be assumed;
S_A – see 9.5.3.7;
z – co-ordinate of the considered point;
p_{ds} – see 9.3.2.2.2.

9.3.2.4 Emergency Condition Pressures

9.3.2.4.1 The design pressure on watertight bulkhead (compartment flooded) shall be determined in accordance with the following formula:

$$p_{d1} = \rho g h_g \text{ [kPa]} \tag{9.3.2.4.1}$$

$\rho = 1.025$ t/m^3.

9.3.2.4.2 The design pressure acting on the inner bottom (double bottom flooded) shall not be less than that determined in accordance with the following formula:

$$p_{d2} = \rho g T \text{ [kPa]} \tag{9.3.2.4.2}$$

$\rho = 1.025$ t/m^3.

This pressure is also the minimum pressure considered at determining the scantlings of plate floors and side girders forming boundaries of the double bottom tanks.

9.3.3 Pressure of liquids in tanks

9.3.3.1 General

If the liquid cargo tanks may be either full or empty, the design pressure acting on the structures forming boundaries of these tanks shall be determined in accordance with the requirements specified in 9.3.3.2. The structures forming boundaries of the tanks are: inner and outer bottom, sides, bilge, decks, platforms, watertight walls (bulkheads) of tanks situated anywhere within the ship space. These structures may form common boundaries of neighbouring tanks and in that case they shall be considered separately, as a boundary of each tank.

9.3.3.2 Pressure of liquid in full tanks

The design pressure for structures forming the boundaries of full tanks shall be taken as the greatest value of $p_6 \div p_{10}$ pressures, determined in accordance with the following formulae:

$$p_6 = (g + 0.5\, a_v)\rho h_a \text{ [kPa]} \tag{9.3.3.2-1}$$

$$p_7 = 0.67\, \rho g h_p \text{ [kPa]} \tag{9.3.3.2-2}$$

$$p_8 = g\rho h_a + p_0 \text{ [kPa]} \tag{9.3.3.2-3}$$

$$p_9 = g\rho \left[0.67\,(h_a + \Theta_A l_a) - 0.12\sqrt{h_z l_s \Theta_A}\right] \text{ [kPa]} \tag{9.3.3.2-4}$$

$$p_{10} = g\rho \left[0.67(h_a + \Phi_A b_a) - 0.12\sqrt{h_z b_s \Phi_A}\right] \text{ [kPa]} \tag{9.3.3.2-5}$$

a_v – acc. to 9.5.4.1;
Φ_A – acc. to 9.5.3.3;
Θ_A – acc. to 9.5.3.2.

Formulae 9.3.3.2-4 and 9.3.3.2-5 shall be applied at dimensioning the structures forming boundaries of cargo or ballast tanks, the length of which exceeds $0.15L_0$ or the maximum breadth exceeds $0.4B$.

Formulae 9.3.3.2-1, 9.3.3.2-4 and 9.3.3.2-5 shall be also used at checking the strength of the inner bottom, sides, decks (platforms), longitudinal and transverse bulkheads forming boundaries of dry cargo holds which are also intended for the carriage of ballast.

9.3.3.3 Pressure of liquid in partly filled tanks

9.3.3.3.1 The pressure in tanks which may be filled between 20% and 90% of the tank height (tank parameters $l_z \leq 0.13L_0$ and $b_z \leq 0.56B$) shall be taken as the greater of the values determined for full tanks, in accordance with 9.3.3.2, and the values not lesser than those determined in accordance with the formulae, respectively:

– for structural members located within $0.25l_z$ from the transverse end bulkheads of the tank:

$$p_{11} = \rho\left(4 - 0.005L_0\right)l_z \quad \text{[kPa]} \qquad (9.3.3.3.1\text{-}1)$$

– for structural members located within $0.25b_z$ from tank longitudinal sides:

$$p_{12} = \rho\left(3 - 0.01B\right)b_z \quad \text{[kPa]} \qquad (9.3.3.3.1\text{-}2)$$

For tanks with parameters $l_z > 0.13L_0$ or $b_z > 0.56B$, the values of pressures p_{11} or p_{12} will be subject to PRS consideration in each particular case.

9.3.3.3.2 The design pressure on girder webs in cargo and ballast tanks shall not be less than 20 kPa.

9.3.3.3.3 The design pressure on transverse and longitudinal wash bulkheads shall be not less than that determined from formulae 9.3.3.3.1-1 and 9.3.3.3.1-2.

9.3.4 Vehicle decks

9.3.4.1 Loads on vehicle decks shall be determined in accordance with subchapter 19.6 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull.*

9.3.4.2 Laminated plating and stiffeners shall comply with the requirements contained in subchapter 9.4.3, based on bending moments and bending of plating, maximum bending moments and shear forces and bending of stiffeners defined in 9.3.4.2.1 and 9.3.4.2.2.

9.3.4.2.1 Plating

Thickness of steel plating t (= t_s) shall be determined in accordance with 19.4.2 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull* for plate geometry as for laminate structure (dimensions of plate sides).

The maximum bending moment for laminate plating, per 1 m of plating width, in place of formula 9.4.3.10.2, shall be determined from the below formula:

$$M_{\max} = 0.25t^2 R_e \quad \text{[Nm/m]} \qquad (9.3.4.2.1)$$

where:

t – net thickness ($t_k = 0$) of steel plating from the formula 19.4.2 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull*, [mm];

R_e – Yield stress of steel taken for calculations, [MPa].

Plate bending values shall be calculated using mechanical methods and theory of laminates, and by assuming different possible layout of wheel print on plate and on neighbouring plates, depending on the kind of carried vehicles.

9.3.4.2.2 Deck beams and logitudinals

Net section modulus of the steel deck beams and longitudinals subjected to wheel load acc. to formula 19.4.3.1 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull* shall be determined for stiffeners support spacing, length and support conditions similar to those of laminate structure.

The below defined moment shall be taken as maximum bending moment for the stiffener in place of formula 9.4.5.6-1:

$$M_{\max} = 0.67 \cdot W \cdot R_e \quad \text{[Nm]} \qquad (9.3.4.2.2\text{-}1)$$

where:

W – net coefficient acc. to formula 19.4.3.1 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull*, [cm^3];

R_e – Yield stress for steel taken for calculations, [MPa].

Maximum shear force for stiffeners, in place of formula 9.4.5.6-2, shall be determined in accordance with the below formula:

$$Q_{max} = 1000Q \ \text{[N]} \qquad (9.3.4.2.2\text{-}1)$$

where:

Q – design load defined acc. to 19.6.3 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull*, [kN]

Bending values for stiffeners shall be determined as for multi-spam beam bent by forces acting from wheels Q (acc. to 19.6.3 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull*) distributed respectively to the kind of vehicles onboard and providing maximum bending of stiffeners.

9.3.4.2.3 Primary supporting members

The requirements of subchapter 9.4.7 shall be complied with.

Wheel loads as for stiffeners shall be taken as a load. Load combinations (vehicle wheel layout) which may really occur and provide maximum bending moments and members deflections shall be considered.

9.3.5 Pillars and supporting members subjected to compressive stresses

9.3.5.1 The requirements of Chapter 13.7 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull* apply to members subjected to compressive axial stresses: deck pillars, vertical stiffeners and bulkhead primary supporting members supporting deck structures, panting beams in peaks and cross-ties in tanks..

9.3.5.2 As far as practicable, the deck pillars shall be fitted in line with the upper and lower pillars.

9.3.5.3 The nominal axial force in deck pillars shall be determined in accordance with the following formula:

$$P = \sum P_i \ \text{[kN]} \qquad (9.3.5.3)$$

P_i – force transmitted to the considered pillar from deck i, [kN].

The force transmitted from deck primary supporting members shall be taken equal to half the sum of lateral forces acting on primary supporting members supported by the considered pillar.

9.3.5.4 Panting Beams

The compressive force of panting beams shall be calculated from the below formula:

$$P = lbp \ \text{[kN]} \qquad (9.3.5.4)$$

l – mean span of a primary supporting member or frame supported by a cross-tie or panting beam, [m];

b – the breadth of the plating supported by a primary supporting member or frame, defined as in 3.2.2.3 of the *Rules for the Classification and Construction of Sea-going Ships, Part II – Hull*, [m].

9.3.6 Longitudinal strength

9.3.6.1 General

9.3.6.1.1 Application

9.3.6.1.1.1 The requirements of 9.3.6 apply to ships of length $L \geq 24$ m (see also 9.3.1.1.1). The final scantlings of the longitudinal hull structure members, which shall comply with the requirements of local strength (Chapter 9.3 and 9.4) shall also satisfy the requirements of hull girder bending and shear strength. These requirements apply to steel ships intended for navigation in unrestricted area. Ships having one or more features given below are subject to PRS consideration in each particular case:

– main dimensions ratios: $L_0/B < 5$; $B/H > 2.5$,

– block coefficient $\delta < 0.6$,

– large deck openings,
– unusual design.

Strength calculations with the use of FE model may be required.

9.3.6.1.1.2 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:

$$M_{wr} = 0.59M_w \text{ [kNm]} \quad (9.3.6.1.1.2\text{-}1)$$

$$Q_{wr} = 0.59Q_w \text{ [kN]} \quad (9.3.6.1.1.2\text{-}2)$$

M_w – vertical wave bending moment, [kNm], determined in accordance with 9.3.6.5;
Q_w – wave component of hull shear force, [kN], determined in accordance with 9.3.6.10.

The modified values of wave hull loads correspond to the values of allowable stresses determined in the present Part of the *Rules*.

9.3.6.1.1.3 The scantlings of the longitudinal members taking part in the longitudinal strength of the hull girder shall comply with the requirements for buckling strength specified in 9.4.

9.3.6.1.1.4 For ships with small block coefficient, high speed and large flare, the section modulus in the forebody may have to be specially considered by PRS based on the distribution of still water and wave bending moments along the ship's length, determined in accordance with 9.3.6.4 and 9.3.6.5. Such procedure is obligatory for ships with speed $v > 17$ knots.

9.3.6.1.1.5 Longitudinal strength of relatively small breadth ships shall be separately considered by PRS, taking into account the combined effects of vertical and horizontal bending of the hull girder.

9.3.6.1.1.6 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. The way of determining the above-mentioned stresses will be separately considered by PRS.

9.3.6.1.1.7 Hull strength assessment shall take into account the assumed changes of the ship ballasting on a voyage which result in the hull load change.

9.3.6.1.2 Symbols

C_w – wave coefficient, as specified in 9.5.2.2.
I_n – moment of inertia of the hull girder 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 plane or strength deck line to the neutral axis of the hull girder, whichever is relevant, [m].
τ – allowable shear stress, [MPa].
σ – allowable normal stress, [MPa].

9.3.6.2 Still water bending moment

9.3.6.2.1 General

9.3.6.2.1.1 Still water bending moments M_s and shear forces Q_s shall be calculated at each section along the ship length for design loading conditions. The design values of M_s and Q_s shall be taken as the maximum values obtained from the above calculation, having regard to the requirements specified in 9.3.6.2.3.

For these calculations, downward loads shall be taken as positive values and shall be integrated in the forward direction from the aft end. The sign conventions of bending moments and shear forces are as shown in Fig. 9.3.6.2.1.1.

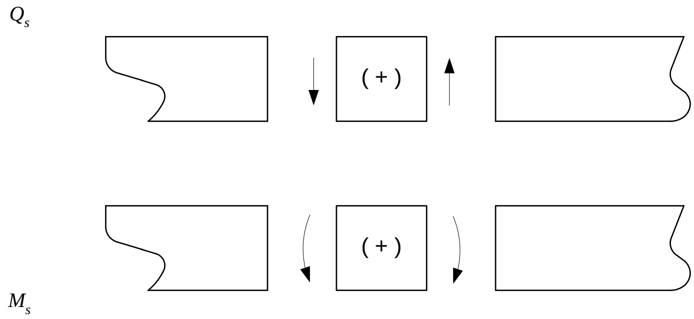


Fig. 9.3.6.2.1.1. Sign conventions of M_s and Q_s

9.3.6.2.1.2 Conditions of minimum and maximum displacement and conditions of maximum bending moments and shear forces at hull hogging and sagging shall be considered as design loading conditions.

9.3.6.2.2 Minimum value of still water bending moment

The minimum value of still water bending moment shall be determined in accordance with the following formula:

$$M_s = M_{so} = 0.006 L_0^3 B(\delta + 0.7) \text{ [kNm]} \quad (9.3.6.2.2)$$

Where absolute value of still water bending moment M_{sl}, determined for ballast condition and, possibly, for conditions with non-homogeneous distribution of load along the ship's length, exceeds M_{so}, then $M_s = M_{sl}$ shall be taken.

The determined value of M_s is applicable within $-0.2L_0 \leq x \leq +0.2L_0$. Beyond this area, M_s may be linearly reduced to zero at $x = -0.5L_0$ and $x = +0.5L_0$.

9.3.6.3 Wave bending moment

9.3.6.3.1 Vertical wave bending moment

The design vertical wave bending moment M_w amidships within $-0.1L_0 < x < +0.15L_0$ shall be taken for negative moment (sagging) as:

$$M_w = M_{wu} = -0.11\, C_w L_0^2 B\, (\delta + 0.7) \text{ [kNm]} \quad (9.3.6.3.1\text{-}1)$$

and for positive moment (hogging) as:

$$M_w = M_{ww} = 0.19 C_w L_0^2 B \delta \text{ [kNm]} \quad (9.3.6.3.1\text{-}2)$$

The following values shall be taken:

$\delta \geq 0.6$;

C_w – see 9.5.2.2.

In harbour conditions, the values of the wave bending moment shall be taken equal to 40% of the values determined above for unsheltered waters and equal to 10% – for sheltered waters.

9.3.6.3.2 Distribution of M_w along ship's length

9.3.6.3.2.1 When values of the wave bending moments M_w at any position along the ship's length are required in connection with stress analysis or buckling control, the applied values M_{wx} shall not be less than the values determined in accordance with the following formula:

$$M_{wx} = k_{wm} M_w, \ \text{[kNm]} \qquad (9.3.6.3.2.1)$$

M_w – as defined in 9.3.6.3.1,
k_{wm} = 1.0 within $-0.1L_0 \le x \le 0.1L_0$,
k_{wm} = 0.0 in sections $x = -0.5L_0$ and $x = +0.5L_0$.

The value of k_{wm} shall be varied linearly between the midship and end areas (see Fig 9.3.6.3.2.2).

9.3.6.3.2.2 For ships with high speed or large flare in the forebody, an adjusted value of k_{wm} shall be taken in formula 9.3.6.3.2.1 within $x \ge +0.1L_0$. 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.

$$C_{av} = \frac{C_v v}{\sqrt{L_0}} \qquad (9.3.6.3.2.2\text{-}1)$$

$$C_{af} = \frac{C_v v}{\sqrt{L_0}} + \frac{F_{pd} - F_{wd}}{L_0 z_{pd}} \qquad (9.3.6.3.2.2\text{-}2)$$

$C_v = \frac{\sqrt{L_0}}{50}$, $C_v \le 0.2$ shall be taken;
L_0 and v – see 1.2.2;
F_{pd} – projected area in the horizontal plane of upper deck, including any forecastle deck, in way of $x \ge +0.3L_0$, [m²];
F_{wd} – area of waterplane at draught T in way of $x \ge +0.3L_0$, [m²];
z_{pd} – vertical distance from the summer load waterline to deck line of the projected deck at F.P., [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 shall not be made.

The adjusted values of k_{wm} are as follows:

– for $C_a \le c_1$
  k_{wm} shall be determined in accordance with 9.3.6.3.2.1 (without adjustment),
– for $C_a \ge c_2$
  k_{wm} = 1.2 for $-0.02\,L_0 \le x \le 0.15\,L_0$,
  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 shall 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 $C_a = C_{af}$

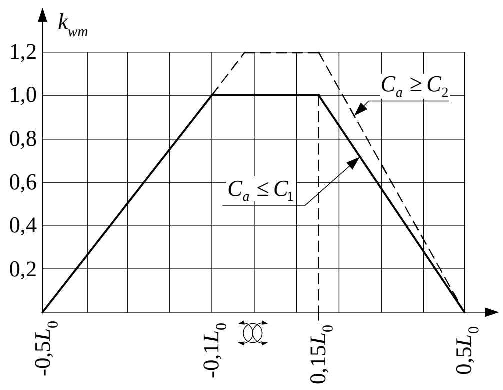


Fig. 9.3.6.3.2.2. Distribution of k_{wm} along the ship's length

9.3.6.3.3 Horizontal wave bending moment

The design horizontal wave bending moment M_{wh} along the ship length shall be determined in accordance with the following formula:

$$M_{wh} = 0.22 L_0^{9/4} (T + 0.3B) \delta \left(1 + \cos\frac{2\pi x}{L_0}\right) \text{ [kNm]} \qquad (9.3.6.3.3)$$

x – coordinate, see Fig. 9.1.2.1.

9.3.6.4 Shear strength

9.3.6.4.1 Application

The requirements of subchapter 9.3.6.4 apply to ships with single or double skin construction of the side shell without effective longitudinal bulkheads.

The shear strength of ships with effective longitudinal bulkheads is subject to PRS consideration in each particular case.

9.3.6.4.2 Still water shear forces

9.3.6.4.2.1 Loading conditions

Still water shear forces Q_s shall be determined at each cross-section of the hull along the ship length for design loading and ballast loading conditions, specified in 9.3.6.2.1.2. For sign conventions, see Fig. 9.3.6.2.1.1.

9.3.6.4.2.2 Distribution of shear forces along ship's length

The design values of still water shear forces, determined in accordance with 9.3.6.4.2.1, shall comply with the following requirements:

$$Q_s \geq k_s Q_{so} \text{ [kN]} \qquad (9.3.6.4.2.2\text{-}1)$$

$$Q_{so} = \frac{5M_{so}}{L_0} \text{ [kN]} \qquad (9.3.6.4.2.2\text{-}2)$$

M_{so} – still water bending moment – see 9.3.6.2.3, [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 values of k_s 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 waived as the design basis for determining the scantlings of hull structural members.

9.3.6.5 Wave shear forces

9.3.6.5.1 The design values of wave shear forces in particular cross-sections of the hull along the ship's length shall be determined in accordance with the following formulae:

$$Q_{wp} = 0.3 k_p C_w L_0 B (\delta + 0.7) \text{ [kN]} \qquad (9.3.6.5.1\text{-}1)$$

$$Q_{wn} = -0.3 k_n C_w L_0 B (\delta + 0.7), \text{ [kN]} \qquad (9.3.6.5.1\text{-}2)$$

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.

Positive internal forces are shown in Fig. 9.3.6.2.1.1.

$k_p = 0$ for $x = -0.5\ L_0$ and $x = +0.5\ L_0$,

$k_p = \dfrac{1.59\delta}{\delta + 0.7}$ for $-0.3\ L_0 \le x \le -0.2\ L_0$,

$k_p = 0.7$ for $-0.1\ L_0 \le x \le +0.1\ L_0$,

$k_p = 1.0$ for $0.2\ L_0 \le x \le +0.35\ L_0$.

The values of k_p are varied linearly in the intermediate regions (see Fig. 9.3.6.5.1).

$k_n = 0$ for $x = -0.5\ L_0$ and $x = +0.5\ L_0$,

$k_n = 0.92$ for $-0.3\ L_0 \le x \le -0.2\ L_0$,

$k_n = 0.70$ for $-0.1L_0 \le x \le +0.1\ L_0$,

$k_n = \dfrac{1.73\delta}{\delta + 0.7}$ for $0.2\ L_0 \le x \le 0.35\ L_0$.

The values of k_n are varied linearly in the intermediate regions (see Fig. 9.3.6.5.1).

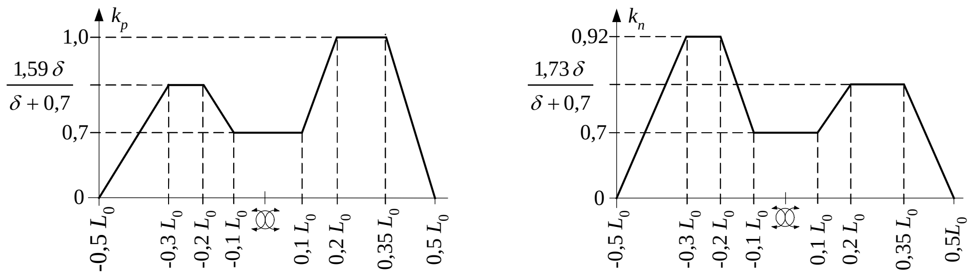


Fig. 9.3.6.5.1. Factors k_p and k_n

9.3.6.5.2 For ships with high speed or large flare in the forebody, the adjusted values of k_p and k_n shall be applied in formulae 9.3.6.5.1-1 and 9.3.6.5.12. 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 9.3.6.5.1, 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 co-ordinate, the value of r shall be determined by linear interpolation C_a, C_{av}, C_{af}, c_1, c_2 – see 9.3.6.3.2.2.

9.4 Scantlings of structural members

9.4.1 General

9.4.1.1 Subchapter 9.4 specifies provisions for strength, rigidity and buckling strength of a ship having laminate or sandwich structure.

9.4.1.2 The method of calculation of strains and stresses in hull structure and of the level of stresses which cause buckling plates, plating stiffeners, primary supporting members and of the whole hull (general strength) are defined in paragraphs 9.4.2 do 9.4.9.

9.4.1.3 The required values of safety factors of hull structure members as regards the stress level and rigidity criteria, the hull structure subjected to design loads shall comply with, are specified in 9.4.3.12, 9.4.4.3.4, 9.4.4.3.5 (for plates) and in 9.4.8 (plating stiffeners, primary supporting members and pillars).

9.4.1.4 The strength calculations required in subchapter 9.4 use the values of strength parameters determined in laboratory tests of specimens made during hull manufacture, i.e. reflecting the structure properties.

During laboratory tests, strength and rigidity parameters (tensile strength, substitute value Young's modulus for plates, stiffeners, etc.) are measured.

9.4.1.5 PRS may agree to performance of strength calculations using the strength parameters (Young's modulus, Poisson's ratio, etc.) given in 9.4.2, 9.4.5 and 9.4.7.

9.4.2 Properties of single layer of laminate

9.4.2.1 General

The method of determining rigidity of a single layer of laminate reinforced by mat, fabric or unidirectional fibre, along any plane direction is defined in 9.4.2.

The rigidity values are used in 9.4.3 for determining rigidity and stresses in plates constructed of single layers, with the use of so called "Classical Lamination Theory"

9.4.2.2 Symbols and co-ordinate systems

It is assumed that the main direction of fabric reinforcement or unidirectional reinforcement covers the direction „1" shown in Fig. 9.4.2.2.

Fig. 9.4.2.2 shows also local *x*-*y* co-ordinate system, in which rigidity of plates constructed of many single layers are defined acc. to 9.4.3.

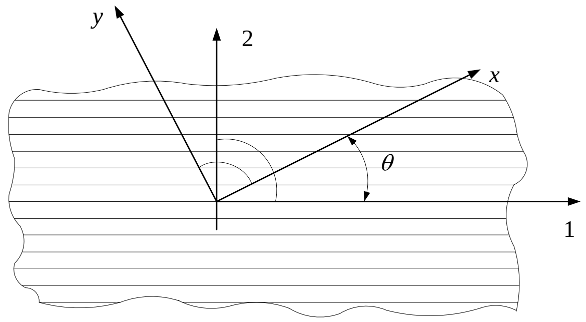


Fig. 9.4.2.2

Symbols used in 9.4.2:

c_m – reinforcement mass content (relative) in single layer of laminate;
c_v – reinforcement volume content (relative) in single layer of laminate;
c_0 – coefficient of warp fibres content in total content of reinforcement of single layer of fabric reinforced laminate (see 9.4.2.7);
E_1 – Young's modulus for single layer with unidirectional reinforcement parallel to fibres direction;
E_2 – as for E_1, but transversely to fibres direction;
ν_{12}, ν_{21} – Poisson's ratio for single layer of laminate in co-ordinate system "12";
G_{12} – modulus of rigidity of the single layer of laminate in co-ordinate system "12";
ρ_{zb} – mass density of laminate reinforcement (e.g. in kg/m^3);
ρ_{zy} – mass density of laminate binder (resin) (e.g. in kg/m^3);
E_{zb1} – Young's modulus of reinforcement fibres along fibres direction;
E_{zb2} – as for E_{zb1}, but transversely to fibres direction;
E_{zy} – Young's modulus of binder (resin);
ν_{z12} – Poisson's ratio of reinforcement fibres material;
ν_{zy} – Poisson's ratio of binder (resin);
G_{zy} – modulus of rigidity of binder (resin);
G_{zb} – modulus of rigidity of reinforcement material;
E_x – Young's modulus of single layer of laminate along *x*-axis (Fig. 9.4.2.2)
E_y – as for E_x, along *y*-axis;
ν_{xy} – Poisson's ratio of single layer of laminate in *x*-*y* co-ordinate system (Fig. 9.4.2.2);
α – angle between *x* and 1 axes (Fig. 9.4.2.2).

9.4.2.3 Thicknesses of single layer of laminate

The relative volume of laminate reinforcement is calculated from the below formula:

$$c_v = \frac{c_m}{c_m + (1 - c_m)\dfrac{\rho_{zb}}{\rho_{zy}}} \qquad (9.4.2.3\text{-}1)$$

Thickness t_1 of single layer of laminate is calculated from the formula:

$$t_1 = m_{zb}\left(\frac{1}{\rho_{zb}} + \frac{1 - c_m}{c_m \cdot \rho_{zy}}\right) \qquad (9.4.2.3\text{-}2)$$

where:

m_{zb} – surface mass of the reinforcement in single layer of laminate (e.g. in kg/m^2).

9.4.2.4 Method of determining rigidity of single layer of laminate

If the values of Young's modulus and Poisson's ratios of single layer of laminate have not been determined by experiment, their values estimated by calculation acc. to the following algorithm may be applied:

a) alternative (dummy) rigidity parameters are calculated for single laminate layer reinforced unidirectionally by a fibre used in hull structure laminate, of the same c_v content as in real reinforcement (by mat, fabric) (see 9.4.2.8);
b) rigidity parameters of single layer of mat reinforced laminate are calculated (p. 9.4.2.6);
c) elasticity parameters are calculated for single laminate layer reinforced by fabric (see 9.4.2.7) and then its rigidity and flexibility matrixes are performed (see 9.4.2.8);
d) rigidity and flexibility matrixes of single laminate layer in *x*-*y* co-ordinate system are calculated (Fig. 9.4.2.2) – acc. to 9.4.2.9.

If parameters of reinforcement and binder material are not specified by experiment nor by manufacturer, the data given in tables 9.4.2.4-1 and 9.4.2.4-2 may be applied in calculations.

Table 9.4.2.4-1
Reinforcement parameters

Parameter \ Material	Glass E	Glass S/R	Carbon HT/HS	Carbon IM	Carbon HM	Aramid fibre
Density, [g/cm^3]	2.54	2.50	1.77 – 1.8	1.8	1.8 – 1.9	1.45
Young's modulus along fibres E_{zb1}, [MPa]	73000	86000	230000	290000	370000	130000
Young's modulus transversely to fibres E_{zb2}, [MPa]	73000	86000	14000	11900	9000	5400
Rigidity modulus G_{zb}, [MPa]	30000	35000	23000	21300	20000	12000
Poissons ratio, [–]	0.18	0.18	0.27	0.25	0.23	0.35
Tensile strength Rm [MPa]	2000÷3000	3000÷4000	3500÷4000	4700÷5600	2600÷4000	3000

Table 9.4.2.4-2
Binder parameters

Parameter \ Binder	Polyester and vinyl ester resin	Epoxy resin
Density ρ_{zy}, [g/cm^3]	1.2	1.2
Young's modulus E_{zy}, [MPa]	3000	3000
Rigidity modulus G_{zy}, [MPa]	1140	1100
Poisson's ratio v_{zy}, [–]	0.32	0.35

9.4.2.5 Parameters of single laminate layer with unidirectional reinforcement

Young's modulus along the reinforcement fibres (direction "1" on Fig. 9.4.2.2 is the reinforcement axis):

$$E_1 = c_v E_{zb1} + (1 - c_v) E_{zy} \qquad (9.4.2.5\text{-}1)$$

Young's modulus taken transversely to fibre direction (direction „2" on Fig. 9.4.2.2):

$$E_2 = \frac{E_{zy}}{1 - \nu_{zy}^2} \cdot \frac{1 + 0.85 c_v^2}{(1 - c_v)^{1,25} + c_v \dfrac{E_{zy}}{E_{zb2}(1 - \nu_{zy}^2)}} \qquad (9.4.2.5\text{-}2)$$

Poisson's ratio in co-ordinate system „12" (Fig. 9.4.2.2):

$$\nu_{12} = c_v \nu_{z12} + (1 - c_v) \nu_{zy} \qquad (9.4.2.5\text{-}3)$$

$$\nu_{21} = \nu_{12} \frac{E_2}{E_1} \qquad (9.4.2.5\text{-}4)$$

Rigidity modulus:

$$G_{12} = G_{zy} \frac{1 + 0.6\, c_v^{0,5}}{(1 - c_v)^{1,25} + \dfrac{E_{zy}}{E_{zb1}} c_v} \qquad (9.4.2.5\text{-}5)$$

where:

$$G_{zy} = \frac{E_{zy}}{2(1 + \nu_{zy})} \qquad (9.4.2.5\text{-}6)$$

9.4.2.6 Parameters of single laminate layer reinforced by mat

Such material is considered isotropic within reinforcement plane.
Young's modulus in lower directions of x, y (Fig.. 9.4.2.2):

$$E_m = E_x = E_y = \frac{3}{8} E_1 + \frac{5}{8} E_2 \qquad (9.4.2.6\text{-}1)$$

where:

E_1, E_2 – Young's modulus calculated acc. to formulae 9.4.2.5-1 and 9.4.2.5.-2, for c_v content of unidirectional fibre reinforcement similar to mat reinforcement.

Poisson's ratio:

$$\nu_m = 0.3 \qquad (9.4.2.6\text{-}2)$$

Rigidity modulus:

$$G_m = \frac{E_m}{2(1 + \nu_m)} \qquad (9.4.2.6\text{-}3)$$

9.4.2.7 Elasticity parameters of single layer of laminate reinforced by fabric

Balanced fabric has main fibres (warp) laid in direction "1" and transverse to them fibres (in direction "2" – see Fig. 9.4.2.2) of smaller surface mass (weft).

The values of Young's modulus E_{t1} and E_{t2} along directions „1" and „2" (Fig. 9.4.2.2) depend on coefficient c_0, being the product of mass density of warp fibres (kg/m^2) and mass density of the whole reinforcement, in the single layer.

Values of E_{t1} and E_{t2} are determined by calculation of coefficients a_1, a_2 and a_{12}:

$$a_1 = c_0 \frac{E_1}{1 - \nu_{12}\nu_{21}} + (1 - c_0) \frac{E_2}{1 - \nu_{12}\nu_{21}} \qquad (9.4.2.7\text{-}1)$$

$$a_2 = c_0 \frac{E_2}{1 - \nu_{12}\nu_{21}} + (1 - c_0) \frac{E_1}{1 - \nu_{12}\nu_{21}} \qquad (9.4.2.7\text{-}2)$$

$$a_{12} = \frac{\nu_{21} E_1}{1 - \nu_{12}\nu_{21}} \qquad (9.4.2.7\text{-}3)$$

where:

E_1, E_2, ν_{12}, ν_{21} – parameters of single unidirectionally reinforced layer, corresponding to single fabric reinforced layer (see 9.4.2.5).

Young's modulus along warp:

$$E_{t1} = a_1 - \frac{a_{12}^2}{a_2} \tag{9.4.2.7-4}$$

Young's modulus along weft:

$$E_{t2} = a_2 - \frac{a_{12}^2}{a_1} \tag{9.4.2.7-5}$$

Rigidity modulus within the layer:

$$G_{t12} = G_{12} \tag{9.4.2.7-6}$$

where:
G_{12} – to be determined according to 9.4.2.5.

Poisson's ratios:

$$\nu_{t12} = \frac{a_{12}}{a_2} \tag{9.4.2.7-7}$$

$$\nu_{t21} = \nu_{t12}\frac{E_{t2}}{E_{t1}} \tag{9.4.2.7-8}$$

9.4.2.8 Rigidity and flexibility matrixes for single laminate layer in co-ordinate system "12"

Relations between stresses and deformations of single laminate layer, within co-ordinate system "12" (fig. 9.4.2.2), may have the below matrix form:

$$\{\sigma\}_{12} = \begin{Bmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{Bmatrix} = [\kappa]_{12}\cdot\{\varepsilon\}_{12} = \begin{bmatrix}\kappa_{11} & \kappa_{12} & 0\\ \kappa_{21} & \kappa_{22} & 0\\ 0 & 0 & \kappa_{33}\end{bmatrix}\begin{Bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{Bmatrix} \tag{9.4.2.8-1}$$

$$\{\varepsilon\}_{12} = \begin{Bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{Bmatrix} = [U]_{12}\cdot\{\sigma\}_{12} = \begin{bmatrix}U_{11} & U_{12} & 0\\ U_{21} & U_{22} & 0\\ 0 & 0 & U_{33}\end{bmatrix}\begin{Bmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{Bmatrix} \tag{9.4.2.8-2}$$

where:
σ_1 – normal stresses along axis „1";
σ_2 – normal stresses along axis „2";
τ_{12} – shear stresses;
ε_1 – normal strains along axis „1";
ε_2 – normal strains along axis „2";
γ_{12} – angle of rigidity deformation;
$[\kappa]_{12}$ – rigidity matrix;
$[U]_{12}$ – flexibility matrix.

Formulae to calculate the rigidity matrix coefficients are given in Table 9.4.2.8-1, and for flexibility matrix coeficients – in Table 9.4.2.8-2.

Table 9.4.2.8-1
Rigidity matrix coefficient

	Single laminate layer with unidirectional reinforcement	Single laminate layer with mat reinforcement	Single laminate layer with fabric reinforcement
κ_{11}	$E_1/(1-\nu_{12}\nu_{21})$	$E_m/(1-\nu_m^2)$	$E_{t1}/(1-\nu_{t12}\nu_{t21})$

κ_{22}	$E_2/(1-\nu_{12}\nu_{21})$	$E_m/(1-\nu_m^2)$	$E_{t2}/(1-\nu_{t12}\nu_{t21})$
κ_{12}	$\nu_{21}E_1/(1-\nu_{12}\nu_{21})$	$\nu_m E_m/(1-\nu_m^2)$	$\nu_{t21}E_{t1}/(1-\nu_{t12}\nu_{t21})$
κ_{21}	$\nu_{12}E_2/(1-\nu_{12}\nu_{21})$	$\nu_m E_m/(1-\nu_m^2)$	$\nu_{t12}E_{t2}/(1-\nu_{t12}\nu_{t21})$
κ_{33}	G_{12}	G_m	G_{t12}

where:
E_1, E_2, ν_{12}, ν_{21}, G_{12} – defined in 9.4.2.5;
E_m, ν_m, G_m – defined in 9.4.2.6;
E_{t1}, E_{t1}, ν_{t12}, ν_{t21}, G_{t12} – defined in 9.4.2.7.

Table 9.4.2.8-2
Flexibility matrix coefficient

	Single laminate layer with unidirectional reinforcement	Single laminate layer with mat reinforcement	Single laminate layer with fabric reinforcement
U_{11}	$1/E_1$	$1/E_m$	$1/E_{t1}$
U_{22}	$1/E_2$	$1/E_m$	$1/E_{t2}$
U_{12}	$-\nu_{21}/E_2$	$-\nu_m/E_m$	$-\nu_{t21}/E_{t2}$
U_{21}	$-\nu_{12}/E_1$	$-\nu_m/E_m$	$-\nu_{t12}/E_{t1}$
U_{33}	$1/G_{12}$	$1/G_m$	$1/G_{t12}$

where: symbols – see Table 9.4.2.8-1.

9.4.2.9 Rigidity and flexibility matrices for single laminate layer in any co-ordinate system

In order to perform analysis of rigidity and strength of laminate plates in accordance with the requirements of 9.4.3, the rigidity matrix $[\kappa]_{xy}$, and flexibility matrix $[U]_{xy}$ of single laminate layer in any co-ordinate system x-y (Fig. 9.4.2.2) situated within the layer plane, shall be developed.

The x, y axes are practically often parallel or perpendicular to the axis of the ship co-ordinate system.

The matrix expressions $[\kappa]_{xy}$, and $[U]_{xy}$ depend on matrix $[\kappa]_{12}$ and $[U]_{12}$ (see 9.4.2.8) and the angle θ (Fig. 9.4.2.2). In the matrix record, this relations may be entered as below:

$$[\kappa]_{xy} = [A][\kappa]_{12}[A']^{-1} \qquad (9.4.2.9\text{-}1)$$

$$[U]_{xy} = [A'][U]_{12}[A]^{-1} \qquad (9.4.2.9\text{-}2)$$

Where: the upper index „–1” means an inverse matrix;

$$[A] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & 2\cos\theta\sin\theta \\ \sin^2\theta & \cos^2\theta & -2\cos\theta\sin\theta \\ -\cos\theta\sin\theta & \cos\theta\sin\theta & \cos^2\theta-\sin^2\theta \end{bmatrix} \qquad (9.4.2.9\text{-}3)$$

$$[A'] = \begin{bmatrix} \cos^2\theta & \sin^2\theta & \cos\theta\sin\theta \\ \sin^2\theta & \cos^2\theta & -\cos\theta\sin\theta \\ -2\cos\theta\sin\theta & 2\cos\theta\sin\theta & \cos^2\theta-\sin^2\theta \end{bmatrix} \qquad (9.4.2.9\text{-}4)$$

Note: in the case of layer reinforced by mat or fabric with warp/weft running along x, y axes, it may be assumed that:

$$[\kappa]_{xy} = [\kappa]_{12} \qquad (9.4.2.9\text{-}5)$$

$$[U]_{xy} = [U]_{12} \qquad (9.4.2.9\text{-}6)$$

9.4.2.10 Strains and stresses destructive for single layer of laminate

The values of strains and stresses destructive for single layer of laminate in the co-ordinate system "12" (Fig. 9.4.2.2), related to unidirectional reinforcement direction, the fabric warp and weft directions or any system situated within the mat reinforcement plane are needed for the strength assessment of plates, stiffeners and primary supporting members made of laminate or sandwich structures.

The values of stresses destructive for single layer of laminate shall be determined from the below formulae:

$$\sigma_{n1} = C_{zy}\ E_1'\ \varepsilon_{n1} \qquad (9.4.2.10\text{-}1)$$

$$\sigma_{n2} = C_{zy}\ E_2'\ \varepsilon_{n2} \qquad (9.4.2.10\text{-}1)$$

$$\tau_{n12} = C_{zy}\ G_{12}'\ \gamma_{n12} \qquad (9.4.2.10\text{-}3)$$

where:

C_{zy} – coefficient depending on the kind of binder:
C_{zy} = 0.8 for polyester resins;
C_{zy} = 0.9 for vinyl ester resins;
C_{zy} = 1.0 for epoxy resins;

E_1' – Young's modulus of laminate layer along direction „1" (Fig. 9.4.2.2), i.e. E_1, E_m or E_{t1} – depending on the reinforcement (symbols used in Table 9.4.2.8-1 and explained below the table).

Table 9.4.2.10
Values of destructive strains

Reinforcement	Type of strain		Type of reinforcement fibres					
			Glass E	Glass S/R	Carbon HS/HT	Carbon IM	Carbon HM	Aramid [3)]
Unidirectional	Tension	ε_{n1}	0.025	0.03	0.012	0.014	0.007	0.017
		ε_{n2} [2)]	0.0042	0.0035	0.0085	0.0065	0.004	0.0065
	Compression	ε_{n1}	0.016	0.016	0.0095	0.0075	0.0045	0.0035
		ε_{n2}	0.0155	0.011	0.023	0.022	0.021	0.02
	Shear	γ_{n12}	0.018	0.015	0.016	0.017	0.018	0.02
Mat	Tension	ε_{n1}	0.015	–	–	–	–	–
		ε_{n2}	0.015	–	–	–	–	–
	Compression	ε_{n1}	0.015	–	–	–	–	–
		ε_{n2}	0.015	–	–	–	–	–
	Shear	γ_{n12}	0.02	–	–	–	–	–
Fabric	Tension	ε_{n1}	0.018	0.023	0.01	0.008	0.0045	0.014
		ε_{n2}	0.018	0.023	0.01	0.008	0.0045	0.014
	Compression	ε_{n1}	0.018	0.015	0.0085	0.008	0.005	0.0042
		ε_{n2}	0.018	0.015	0.0085	0.008	0.005	0.0042
	Shear	γ_{n12}	0.015	0.015	0.0155	0.016	0.0185	0.023

Notes:

1. Stresses and strains destructive for laminate as interlaminar shear will be subject to separate PRS consideration. At typical dimensional proportions of plates used in hull structures, the strength in interlaminar shear conditions is satisfactory, i.e. earlier occurs destruction due to strains/stresses in the reinforcement plane. See also 9.4.3.6.
2. For all kinds of fibres, the criterion ε_{n2} for tension of unidirectional fibres may be exceeded if it has been assumed in calculations that $\sigma(\varepsilon_{n2}) = 0$, and the fibres have no contact with water and other fluids. Where such contact exists and ε_2 for tension exceeds the value of 0.002, the unidirectional layer shall be an internal layer of laminate. The condition $\sigma(\varepsilon_{n2}) = 0$ for tension means that on direction 2 the load carrying fibres shall be applied instead of unidirectional reinforcement.
3. In the case of compression of aramid reinforcement layer along fibres (unidirectional reinforcement, fibres), when the aramid reinforcement layers disperse in the glass and/or carbon reinforcement layers, PRS accepts exceeding permissible strains by $1/3\varepsilon_{n1}$ for tension (exceeding ε_{n1} for tension means buckling of fibres in the elastic binder – for production typical fibres content in laminate), with the condition that the destructive load related to all layers (the whole thickness of laminate), i.e.

bending moment and compression force, are three times greater than design loads. The detailed algorithm of such calculations will be subject to separate consideration by PRS.

The values ε_{n1}, ε_{n2}, γ_{n12} given in Table 9.4.2.10 are relative strains defined as below:

$$\varepsilon_{n1} = \frac{R_1}{E_1}\,;\ \varepsilon_{n2} = \frac{R_2}{E_2}\,;\ \gamma_{n12} = \frac{R_{t12}}{G_{12}}$$

where:
R_1, R_2 – tensile or compression strength of reinforcement layer along directions 1 and 2;
R_{t12} – compression strength of reinforcement layer;
E_1, E_2 – Young's modulus along direction 1 or 2 at tension or compression,
G_{12} – rigidity modulus of reinforcement layer.

When strength tests of test specimens prove lower values of ε_{n1}, ε_{n2}, γ_{n12} than given in Table 9.4.2.10, test data shall be taken for calculations.

If test results show higher parameters of laminate, PRS may consider their use in calculations.

9.4.3 Rigidity and strength of laminate plating

9.4.3.1 General principles and assumptions

9.4.3.1.1 Paragraph 9.4.3 specifies assessment methods for strength and rigidity of laminate or sandwich plating used in hull, deck, bulkhead, etc. plating, subject to local loads due to sea pressure, pressure of liquids in tanks, deck loads, etc and transferring hull general bending stresses.

9.4.3.1.2 It is assumed that the plate consists of some number of single layers (see 9.4.3.4) or is a sandwich structure.

9.4.3.1.3 Paragraph 9.4.3 specifies formulae used to estimate the maximum values of bending moments in a plate bent due to pressure, the values of compression forces (essential for plates of sandwich structure) and plate deflections.

Plate stresses and deflections criteria for local bending conditions are also specified.

9.4.3.2 Internal forces in a plate

The internal forces acting in a plate, distributed continuously along its side edges, reduced to the middle thickness plane, are shown in Fig. 9.4.3.2.

The Fig. 9.4.3.2 shows also the *xyz* co-ordinate system related to the plate.

The senses of internal forces shown in Fig. 9.4.3.2 and deflection $w(x, y)$ of the middle layer of the plate, shall be considered positive.

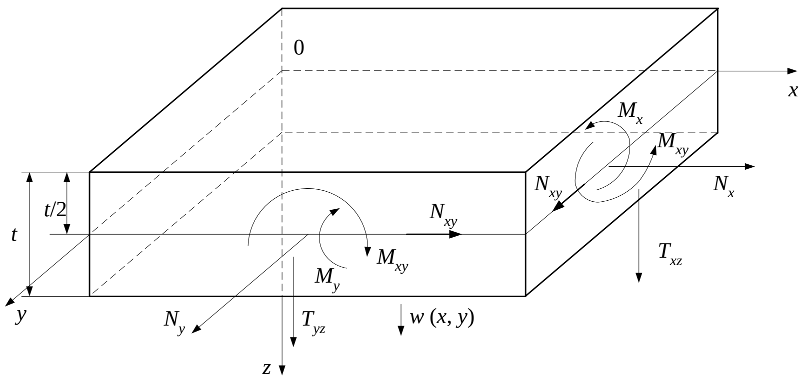


Fig. 9.4.3.2

The internal forces shown in Fig 9.4.3.2 have the following meaning:
N_x, N_y – normal (longitudinal) forces along x and y axes;
N_{xy} – shear forces;
M_x, M_y – bending moments with senses towards directions y and $-x$;

M_{xy} – torsional moments (due to stresses τ_{xy} and τ_{yx});
T_{xz}, T_{yz} – transverse (shear) forces.

9.4.3.3 Plate strains

The below symbols of plate strains shall be obligatorily used:

ε_{x0}, ε_{y0} – normal strain along x and y axes in the middle layer of plate;
γ_{xy0} – non-dilatational strain angle in the middle layer of plate;
$\varepsilon_x, \varepsilon_y, \gamma_{xy}$ – z strains in the layer (co-ordinate system $0xyz$ shown in Fig. 9.4.3.2);
$\kappa_x = -\dfrac{\partial^2 w}{\partial x^2}$ – curvature of strained plate in xz plane;
$\kappa_y = -\dfrac{\partial^2 w}{\partial y^2}$ – curvature of strained plate in yz plane;
$\kappa_{xy} = -2\dfrac{\partial^2 w}{\partial x \partial y}$ – strains due to plate torsion.

The below relations defining plate layer strains of z co-ordinate shall be applied:

$$\varepsilon_x = \varepsilon_{x0} + \kappa_x\, z \qquad (9.4.3.3\text{-}1)$$

$$\varepsilon_y = \varepsilon_{y0} + \kappa_y\, z \qquad (9.4.3.3\text{-}2)$$

$$\gamma_{xy} = \gamma_{xy0} + \kappa_{xy}\, z \qquad (9.4.3.3\text{-}3)$$

9.4.3.4 Assumed arrangement of plate layers

It is assumed that the plate of thickness t is composed of n single layers (Fig. 9.4.3.4).

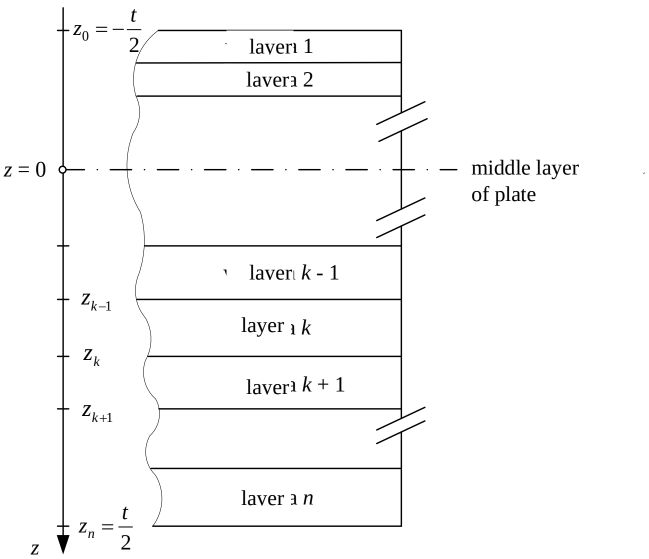


Fig. 9.4.3.4. Assumed arrangement of plate layers

9.4.3.5 Relation between internal forces and plate strains

The below relations applies (in matrix notation:

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} [C] & [B] \\ [B] & [D] \end{bmatrix} \begin{Bmatrix} \varepsilon_{x0} \\ \varepsilon_{y0} \\ \gamma_{xy0} \\ \kappa_x \\ \kappa_y \\ \kappa_z \end{Bmatrix} \qquad (9.4.3.5\text{-}1)$$

where:
N_x, N_y, N_{xy}, M_x, M_y, M_{xy} – internal forces (see Fig. 9.4.3.2);
ε_{x0}, ε_{y0}, γ_{xy0} ,κ_x, κ_y, κ_z – strains defined in 9.4.3.3;
[C], [B], [D] – matrices 3×3, defining rigidity of laminar plate, whose expressions are determined according to below formulae.

$$C_{ij} = \sum_{\kappa=1}^{n} \left(\kappa_{ij,xy}\right)_k \cdot \left(z_k - z_{k-1}\right) \tag{9.4.3.5-2}$$

where:
n, z_k, z_{k-1} – are shown in Fig. 9.4.3.2;
$(\kappa_{ij,\,xy})_k$ – expressions of rigidity matrix $[\kappa]_{xy}$ of k laminate layer, defined in x-y co-ordinate system (Fig. 9.4.3.2), acc. to formula 9.4.2.9-1;
i = 1, 2, 3;
j = 1, 2, 3;

$$B_{ij} = \frac{1}{2} \sum_{k=1}^{n} \left(\kappa_{ij,\,xy}\right)_k \left(z_k^2 - z_{k-1}^2\right) \tag{9.4.3.5-3}$$

where:
symbols – see formula 9.4.3.5-2;

$$D_{ij} = \frac{1}{3} \sum_{k-1}^{n} \left(\kappa_{ij,xy}\right)_k \left(z_k^3 - z_{k-1}^3\right) \tag{9.4.3.5-4}$$

where:
symbols – see formula 9.4.3.5-2.

Strains of the plate middle layer in relation to internal forces are determined by transformation of formula 9.4.3.5-1:

$$\begin{Bmatrix} \varepsilon_{x0} \\ \varepsilon_{y0} \\ \gamma_{xy0} \\ \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix} = \begin{bmatrix} [C] & [B] \\ [B] & [D] \end{bmatrix}^{-1} \begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} \tag{9.4.3.5-5}$$

The values of strains in the middle of thickness of k layer of laminate are determined based on the formulae 9.4.3.3-1 to 9.4.3.3-3 and Fig. 9.4.3.2):

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}_k = \begin{Bmatrix} \varepsilon_{x0} \\ \varepsilon_{y0} \\ \gamma_{xy0} \end{Bmatrix} + \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix} \cdot \frac{z_{k-1} + z_k}{2} \tag{9.4.3.5-6}$$

The strains in co-ordinate system „12", defining characteristic directions of reinforcement of k layer of laminate (Fig. 9.4.2.2), shall be determined from the formula:

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix}_k = \left[A'\right]^{-1} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}_k \tag{9.4.3.5-7}$$

where:
$[A']$ – defined by formula 9.4.2.9-4;

$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}_k$ – see formula 9.4.3.5-6.

The strains in k layer of laminate in the co-ordinate system „12" (Fig. 9.4.2.2) shall be determined form the formula:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix}_k = [\kappa]_{12,k} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix}_k \qquad (9.4.3.5\text{-}8)$$

where:

$[\kappa]_{12,k}$ – rigidity matrix of k layer defined as $[\kappa]_{12}$ in 9.4.2.8.

Stresses σ_1, σ_2, τ_{12} are used to the strength assessment of k layer of laminate by comparing them with the values defined by formulae 9.4.2.10-1 to 9.4.2.10-3, divided by safety factors defined in 9.4.3.12.

Note: for plates of single layers laid symmetrically against its middle plane, $[B]$ is a matrix of zero expressions.

9.4.3.6 Interlaminar shear of plate

The level of shear stresses τ_{zx} and τ_{zy} between particular plate layers depends on internal forces T_{xz} and T_{yz} (Fig. 9.4.3.2).

Notes given at the end of 9.4.2.10 apply.

The below values may be taken for initial estimations of the maximum level of stresses τ_{zx} and τ_{zy}:

$$\tau_{zx} < 1.5\, T_{xz} / t \qquad (9.4.3.6\text{-}1)$$

$$\tau_{zy} < 1.5\, T_{yz} / t \qquad (9.4.3.6\text{-}2)$$

9.4.3.7 Laminate plate rigidity in its plane

Substitute values of Young's modulus along x and y axes (Fig. 9.4.3.2) shall be calculated from the below formulae:

$$E_x = \frac{1}{C'_{11} \cdot t} \qquad (9.4.3.7\text{-}1)$$

$$E_y = \frac{1}{C'_{22} \cdot t} \qquad (9.4.3.7\text{-}2)$$

where:

C'_{11} and C'_{22} – expressions of square matrix in formula 9.4.3.5-5, with indexes 11 and 22;

t – laminate plate thickness (Fig. 9.4.3.2).

Substitute value of plate (shear) rigidity module in the x-y plane (Fig. 9.4.3.2) shall be calculated from the formula:

$$G_{xy} = \frac{1}{C'_{33} \cdot t} \qquad (9.4.3.7\text{-}3)$$

where:

C'_{33} – the expression of a square matrix in formula 9.4.3.5-5, with index 33;

t – laminate plate thickness (Fig. 9.4.3.2).

The co-ordinates $z = z_n$ of neutral layer of plate at its tension/compression along x and y axes shall be calculated from the below formulae (the z axis is shown in Fig 9.4.3.2):

$$z_{nx} = \frac{\sum_{k=1}^{n} E_{xk} t_{\kappa} (z_k + z_{k-1})/2}{\sum_{k=1}^{n} E_{xk} t_k} \qquad (9.4.3.7\text{-}4)$$

$$z_{ny} = \frac{\sum_{k=1}^{n} E_{yk} t_k (z_k + z_{k-1})/2}{\sum_{k=1}^{n} E_{yk} t_k} \qquad (9.4.3.7\text{-}5)$$

where:

E_{xk}, E_{yk} – equivalent values of Young's modules for a single layer of laminate respectively equal to $1/U_{xy11}$ and $1/U_{xy22}$ (U_{xy11} and U_{xy22} – expressions of matrix $[U]_{xy}$ defined by equation 9.4.2.9-2, with indexes 11 and 12);

z_{k-1}, z_k – see Fig. 9.4.3.2;

$t_k = z_k - z_{k-1}$.

Notes:

1) For plate consisting of mat reinforced similar layers, the below may be assumed:

$$E_x = E_y = E_m \qquad (9.4.3.7\text{-}6)$$

$$G_{xy} = G_m \qquad (9.4.3.7\text{-}7)$$

2) For plate of single layers arranged symmetrically to its middle plane, with mat or fabric reinforcement having warp/weft along x or y axis, the below may be taken:

$$E_x = \frac{1}{t} \sum_{k=1}^{n} (E_{ti})_k \cdot (z_k - z_{k-1}) \qquad (9.4.3.7\text{-}8)$$

$(E_{ti})_k = E_{t1}$ – when warp direction of k-layer is along x axis;

$(E_{ti})_k = E_{t2}$ – when warp direction of k-layer is along y axis;

$(E_{ti})_k = E_m$ – for mat reinforced layer.

E_y shall be calculated similar to E_x.

$$G_{xy} = \frac{1}{t} \sum_{k=1}^{n} (G)_k \cdot (z_k - z_{k-1}) \qquad (9.4.3.7\text{-}9)$$

where:

$(G)_k$ means the rigidity module G_{t12} of k-layer reinforced with fabric or the rigidity module G_m of k-layer reinforced with chopped strand mat.

3) For plate of single layers arranged symmetrically to its middle plane, the below may be assumed:

$$z_{nx} = z_{ny} = 0 \qquad (9.4.3.7\text{-}10)$$

(the z axis is shown in Fig. 9.4.3.2).

9.4.3.8 Laminate plate bending rigidity

The rigidities of laminate plates used for calculation of plate deflections due to bending moments M_x and M_y (Fig. 9.4.3.2) have the below values:

$$EI_x = \frac{1}{D'_{11}} \qquad (9.4.3.8\text{-}1)$$

$$EI_y = \frac{1}{D'_{22}} \qquad (9.4.3.8\text{-}2)$$

where:

D'_{11}, D'_{22} expressions of a square matrix found in equation 9.4.3.5-5, with indexes 44 and 55.

Notes:

1) For plate consisting of mat reinforced similar layers, the below may be assumed:

$$EI_x = EI_y = \frac{E_m \cdot t^3}{12(1-\nu_m^2)} \qquad (9.4.3.8\text{-}3)$$

(E_m, ν_m – defined in 9.4.2.6).

2) For plate of single layers arranged symmetrically to its middle plane, with mat or fabric reinforcement having warp/weft along x or y axis, the below may be taken:

$$EI_x = \sum_{k=1}^{n} \frac{1}{3} \frac{(E_{ti})_k}{(1-\nu_{12} \cdot \nu_{21})} \cdot (z_k^3 - z_{k-1}^3) \qquad (9.4.3.8\text{-}4)$$

where:
k, $(E_{ti})_k$, z_k, z_{k-1} – as in 9.4.3.7;
ν_{12}, ν_{21} – respectively ν_{t12} and ν_{t21} for fabric reinforced layer, or
$\nu_{12} = \nu_{21} = \nu_m$ – for mat reinforced layer (ν_{t12}, ν_{t21}, ν_m – defined in 9.4.2.8).
EI_y shall be determined similar to EI_x.

9.4.3.9 Dimensions of plates and boundary conditions at local bending

9.4.3.9.1 Effective span s of a plate perpendicular to stiffeners axis shall be determined as a distance between centres of tee bar or angle bar stiffeners or between axes of trapezoid stiffeners cross-sections (Fig. 9.4.3.9.1).

For curved plating, s shall be determined in accordance with 9.4.3.9.3.

When the geometry and thickness of trapezoid stiffening webs considerably affects reduction of bending moments of plating, PRS may on individual basis allow for lower breadth s of plate than shown in Fig. 9.4.3.9.1.

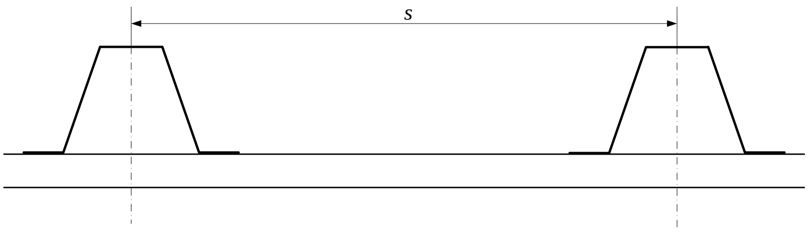


Fig. 9.4.3.9.1

Plate elongation coefficient a_w, considered at calculation of the plate internal forces and bending (see 9.4.3.10 and 9.4.3.11) shall be determined from the below formula:

$$a_w = \frac{s}{l} \qquad (9.4.3.9.1\text{-}1)$$

where:
s – defined as above;
l – the distance between supported plate edges, measured along stiffeners axis; $l \geq s$ is assumed.

For plates having orthotropic properties, adjusted value a_w shall be applied, calculated from the formula:

$$a_{wk} = \frac{s}{l} \sqrt[4]{\frac{EI_y}{EI_x}} \qquad (9.4.3.9.1\text{-}2)$$

where:
s, l – as in formula 9.4.3.9.1-1;
EI_x, EI_y – defined in 9.4.3.8.

9.4.3.9.2 In the case of plating parts of regular structure (constant spacing of stiffeners and primary supporting members) loaded by pressure, it may be assumed for calculations that edges of single plate (between adjacent stiffeners and primary supporting members) are fixed.

In other cases it is recommended to adopt simple support of the single plate edge or to perform calculations of strains and internal forces in the plating, using FE model of hull structure.

9.4.3.9.3 For curved plating, the effective plate span *s* shall be determined in accordance with Fig. 9.4.3.9.3.

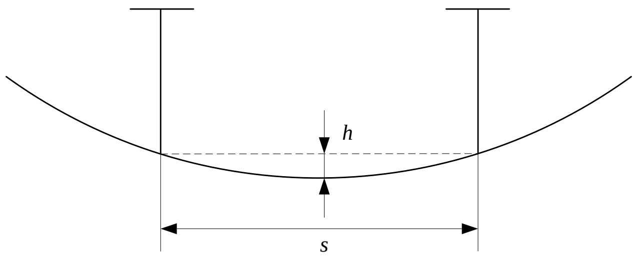


Fig. 9.4.3.9.3

The correction factor r_κ applied at calculation of internal forces in curved plating (see 9.4.3.10) shall be determined from the below formula (for $0.03 < h/s < 0.1$).

$$r_\kappa = 1.15 - 5\frac{h}{s} \qquad (9.4.3.9.3\text{-}1)$$

where:
h, *s* – acc. to Fig. 9.4.3.9.3.
It shall be assumed that:

$$r_\kappa \geq 0.65 \qquad (9.4.3.9.3\text{-}2)$$

9.4.3.10 Internal forces and stresses in bent plates

9.4.3.10.1 Formulae given in 9.4.3.10.2 to 9.4.3.11 apply to monolithic or sandwich plates loaded by pressure, ignoring membrane effects (tension/compression linked with bending).

Design calculations of hull structure including membrane effects will be subject to separate consideration by PRS.

9.4.3.10.2 The maximum value M_{max} of bending moment M_x in a plate (Fig. 9.4.3.2; the *x* axis is carried along effective span *s* of plate – see Figs. 9.4.3.9.1 and 9.4.3.9.3) is found:
- in case of plates of fixed edges: at axes of plating stiffeners in the middle of longer plate edges;
- in case of plates of simply supported edges: in the plate geometrical centre.

The M_{max} value shall be calculated from the formula:

$$M_{max} = c_M \frac{p\,s^2}{12} r_k \qquad (9.4.3.10.2)$$

where:
c_M – coefficient of the values depending on *s*/*l* relation, given in Table 9.4.3.10.2;
p – design pressure;
s – effective span, defined in accordance with 9.4.3.9.1;
r_k – correction factor, acc. to 9.4.3.9.3.

Table 9.4.3.10.2
Values of c_M

Values $\frac{1}{a_w} = \frac{l}{s}$	1	1.2	1.4	1.6	1.8	2	3	4	5	∞
c_M – for plates with simply supported edges	0.58	0.76	0.90	1.04	1.14	1.22	1.42	1.48	1.48	1.5
c_M – for plates with fixed edges	0.62	0.76	0.88	0.94	0.98	1.0	1.0	1.0	1.0	1.0

Note: for intermediate values $a_w = s/l$, c_M to be determined by linear interpolation.

9.4.3.10.3 Stresses, σ_x, due to moment M_{max}, (see 9.4.3.10.2) shall be determined from the below algorithm:

a) Determine the strains ε_x:

$$\varepsilon_x = \frac{M_{\max}}{EI_x} z \qquad (9.4.3.10.3\text{-}1)$$

where:
$M_{\max}$ – bending moment acc. to 9.4.3.10.2;
EI_x – plate bending rigidity acc. to 9.4.3.8;
z – distance to neutral layer (the position of neutral layer to be determined acc. to 9.4.3.7).
To be assumed:

$$\varepsilon_y = \gamma_{xy} = 0 \qquad (9.4.3.10.3\text{-}2)$$

b) calculate strains ε_1, ε_2, γ_{12} in co-ordinate systems „12" of individual plate layers (Fig. 9.4.2.2), acc. to formula 9.4.3.5-7;
c) determine stresses σ_1, σ_2, τ_{12} in co-ordinate systems „12" of individual plate layers, acc. to formula 9.4.3.5-8;
d) determine strains and stresses destructive for particular laminate layers, acc. to 9.4.2.10.

Note: for plates of symmetrical construction, considered in end parts of 9.4.3.7 i 9.4.3.8, the below values may be taken directly:

$$\varepsilon_1 = \varepsilon_x \text{ or } \varepsilon_1 = \varepsilon_y \qquad (9.4.3.10.3\text{-}3)$$

$$\varepsilon_2 = \varepsilon_y \text{ or } \varepsilon_2 = \varepsilon_x \qquad (9.4.3.10.3\text{-}4)$$

Depending on the warp/weft direction.

9.4.3.10.4 The maximum value of plate shear force (forces T_{xz} and T_{yz} in Fig. 9.4.3.2), acting at plate stiffeners in the middle part of the longer edge of plate, shall be calculated from the formula:

$$N_{\max} = c_N \, p \, s \qquad (9.4.3.10.4\text{-}1)$$

where:
c_N – coefficient with values taken depending on s/l relation, given in Table 9.4.3.10.4;
p, s – as in 9.4.3.10.2.

Table 9.4.3.10.4
Values of c_N

Values $\frac{1}{a_w} = \frac{l}{s}$	1	1.2	1.4	1.6	1.8	≥ 2
c_N – for plates with fixed edges	0.42	0.46	0.48	0.49	0.50	0.50
c_N – for plates with simply supported edges	0.42	0.46	0.48	0.49	0.50	0.50

Note: c_N for intermediate values of $a_w = s/l$ shall be determined by linear interpolation.

The shear stresses used in the strength assessment of sandwich structure core, made of isotropic material (e.g. foam), shall be calculated from the formula:

$$\tau = \frac{N_{\max}}{t_r + 0.5(t_1 + t_2)} \qquad (9.4.3.10.4\text{-}2)$$

where:
$N_{\max}$ – transverse force, calculated from formula 9.4.3.10.4-1;
t_r – core thickness;
t_1, t_2 – thickness of linings.

9.4.3.11 Plate deflection

Deflection of the middle part of plate loaded with pressure p on the whole surface, shall be calculated from the formula:

$$f_p = c_f \frac{p\, s^4}{12 EI_x} \qquad (9.4.3.11)$$

where:
c_f – coefficient with values depending on s/l relation, given in Table 9.4.3.11;

p,s – as in 9.4.3.10.2;
EI_x – rigidity of plate bending, acc. to 9.4.3.8.

Table 9.4.3.11
Values of c_f

Values $\frac{1}{a_w} = \frac{l}{s}$	1	1.2	1.4	1.6	1.8	2	3	≥ 4
c_f – for plates with fixed edges	0.01	0.02	0.02	0.03	0.03	0.03	0.03	0.03
c_f – for plates with simply supported edges	0.04	0.06	0.08	0.09	0.10	0.11	0.13	0.14

Note: c_f for intermediate values of $a_w = s/l$ shall be determined by linear interpolation.

9.4.3.12 Plate rigidity and strength criteria

9.4.3.12.1 Hull plating shall comply with the rigidity criterium defined in 9.4.3.12.2, strength criteria defined in 9.4.3.12.3 and 9.4.3.12.4, as well as buckling criterium defined in 9.4.4.3.4 and 9.4.4.3.5.

9.4.3.12.2 The maximum deflection value f_p of plating between neighboring stiffeners, under pressure of design value defined in 9.5, shall comply with the below condition:

$$\frac{f_p}{s} \leq c_p \qquad (9.4.3.12.2)$$

where:
s – effective plate span defined in 9.4.3.9.1 and 9.4.3.9.3;
c_p – coefficient of values:
$c_p = 0.015$ – for laminate plates,
$c_p = 0.01$ – for sandwich plates.

The deflection values f_p shall be calculated using mechanics methods and laminate theory. For rectangular plates loaded with pressure p = const on the whole surface, f_p may be calculated acc. to formula 9.4.3.11.

For some parts of hull structure, PRS, after separate consideration, may agree to use greater values of c_p than specified below.

9.4.3.12.3 For laminate plates or sandwich structure linings, the strength criterium consists in comparing the values of strains or stresses with their destructive values.

After defining internal forces acting in the plate (Fig. 9.4.3.2), strains in particular plate layers shall be determined in the co-ordinate system „12" (Fig. 9.4.2.2) by using succesively formulae 9.4.3.5-5 to 9.4.3.5-7.
Note: in formula 9.4.3.5-5, forces N_x, N_y and N_{xy} result normally from bending primary supporting members (see 9.4.7) or general bending of hull (9.4.9). Forces M_x, M_y and M_{xy} are the result of local bending of plates.

For points in the middle part of plate, along its length l:
$M_y = M_{xy} = 0$ – in points of edges supported without stiffening;
$M_{xy} = 0$ – in the middle point of plate (additionally: $M_y = 0$ when $l/s > 2$).

Each of calculated strains ε_1, ε_2, γ_{12} in each laminate layer shall be not more than 1/3 of destructive value, defined in 9.4.2.10.

Alternatively, the values of stresses σ_1, σ_2, τ_{12} in each laminate layer, calculated acc. to formula 9.4.3.5-8, shall be not more than 33% of stresses respectively equal to σ_{n1}, σ_{n2}, τ_{n12}, calculated from formulae 9.4.2.10-1 to 9.4.2.10-3.

The level of stresses, τ_{zx} and τ_{zy}, (interlaminar shear), calculated acc. to 9.4.3.6, shall be not more than 20% of destructive value.

9.4.3.12.4 For sandwich plate cores, the level of stresses τ calculated from the formula 9.4.3.10.4-2 shall be not higher than 40% of destructive value determined by experiment or provided by the manufacturer.

9.4.4 Plates buckling

9.4.4.1 General

9.4.4.1.1 The requirements of 9.4.4 apply to calculation of the level of compressive or shear strains of laminate (or sandwich) plates, at which elasticity buckling occurs, and to criteria to be fulfilled (see 9.4.4.3.4 and 9.4.4.3.5).

9.4.4.1.2 The buckling normally occurs as global deflection of plate or corrugation of sandwich plate linings. Other forms of buckling sandwich plate, which can occur at specific construction, will be separately considered by PRS.

9.4.4.2 Buckling as corrugation of sandwich plate linings

9.4.4.2.1 The possibility of buckling in the form of linings corrugation shall be considered in the case when at least one of linings is compressed.

9.4.4.2.2 For sandwich plates with monolithic isotropic core (e.g. foam core), the level of relative (compressive) strains which cause corrugation, shall be calculated from the formula:

$$\varepsilon_c = 0.5\sqrt[3]{E_{01}E_r G_r} / E_0 \qquad (9.4.4.2.2)$$

where:

E_{01} – substitute value of Young's modulus of the lining for bending (in direction of compression); for multi-layer lining of balanced structure (when matrix [B] defined in 9.4.3.5 has zero value), E_{01} may be taken as substitute value to E_0 value of Young's modulus of compressed lining plate (see formulae 9.4.3.7-1 and 9.4.3.7-2);

E_r – Young's modulus of the core material in compression;

G_r – modulus of rigidity of core material.

9.4.4.2.3 For sandwich plate having core of „honeycomb" structure, the level of relative (compressive) strains at which corrugation occurs, shall be calculated from the formula:

$$\varepsilon_c = 0.6\sqrt{E_{01}E_r\frac{t_0}{t_r}} \Big/ E_0 \qquad (9.4.4.2.3)$$

where:

E_{01}, E_0, E_r – as defined in 9.4.4.2.1;

t_0 – thickness of lining;

t_r – thickness of core.

9.4.4.3 Buckling of compressed or sheared plates

9.4.4.3.1 Global buckling of sandwich or monolithic structure plate may occur in compression or shear conditions.

The formulae for calculation of the level of critical strains, given in 9.4.4.3.2 and 9.4.4.3.3, apply to plates of balanced structure (compression – bending feedback does not occur, i.e. the matrix [B] defined in 9.4.3.5 has zero value), supported on the whole periphery.

For sandwich plates, formulae in 9.4.4.3.2 and 9.4.4.3.3 apply when the below conditions are fulfilled:

$$0.8 \le \frac{E_{x,g}\cdot t_g}{E_{x,d}\cdot t_d} < 1.2 \qquad (9.4.4.3.1\text{-}1)$$

$$0.8 \le \frac{E_{y,g}\cdot t_g}{E_{y,d}\cdot t_d} \le 1.2 \qquad (9.4.4.3.1\text{-}2)$$

where:

$E_{x,g}$, $E_{x,d}$ – substitute values of Young's modulus for the top and bottom lining along "*x*" direction (along the plate side), calculated from formulae 9.4.3.7-1;

t_g, t_d – thickness of top and bottom lining;

$E_{y,g}$, $E_{y,d}$ – as for $E_{x,g}$, $E_{x,d}$, along "*y*" axis (along the second side of plate).

If the above conditions and restrictions are not fulfilled, the level of critical strains will be separately assessed by PRS.

9.4.4.3.2 The level of relative critical (normal) strains when plate buckling occurs in unidirectional compression conditions (Fig. 9.4.4.3.2) shall be calculated from the below formula:

$$\varepsilon_c = \frac{1}{E\,t} c \left(\frac{\pi}{\mathrm{b}}\right)^2 \sqrt{D_{11} \cdot D_{22}} \qquad (9.4.4.3.2\text{-}1)$$

where:

E – substitute value of Young's modulus of the plate along compression axis (along the side of length a), calculated from formula 9.4.3.7-1 or 9.4.3.7-2;
t – total thickness of monolithic or sandwich plate;
b – length of plate side transversely to compression axis;
D_{11},D_{22} – plate bending rigidity coefficients, calculated from formula 9.4.3.5-4; directions "1" and "2" are shown in Fig. 9.4.4.3.2;
$c = c_1 + c_2 \cdot \beta$
c_1 – coefficient of values depending on the substitute coefficient α of plate slenderness and on the method of supporting the plate edges, defined from Table 9.4.4.3.2;

$$\alpha = \frac{a}{b} \sqrt[4]{\frac{D_{22}}{D_{11}}}$$

$c_2 = 2$ – when the plate edges parallel to compression axis are simply supported;
$c_2 = 2.36$ – when the plate edges parallel to compression axis are fixed;

$$\beta = \frac{D_{12} + 2D_{33}}{\sqrt{D_{11} \cdot D_{22}}}$$

D_{11}, D_{22}, D_{12}, D_{33} – coefficients of plate bending rigidity calculated from formula 9.4.3.5-4

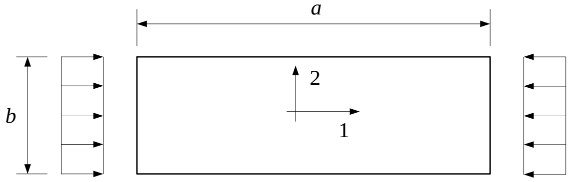


Fig. 9.4.4.3.2. Plate compressed unidirectionally

Table 9.4.4.3.2
Values of coefficient c_1

Method of supporting plate edges	α									
	0.4	0.5	0.6	0.7	1.0	1.5	2.0	2.5	3.0	≥ 3.5
All edges simply supported	7.5	4.3	3.0	2.4	2.0	2.0	2.0	2.0	2.0	2.0
Loaded (compressed) edges fixed, non-loaded edges simply supported	–	–	–	9.5	4.6	3.2	2.8	2.5	2.3	2.2
Loaded (compressed) edges simply supported, non-loaded edges fixed	7.5	5.8	5.0	4.6	4.6	4.6	4.6	4.6	4.6	4.6
All edges fixed	–	–	–	9.5	7.1	5.9	5.5	5.1	5.0	4.9

Note: for intermediate values of α, linear interpolation shall be applied.

9.4.4.3.3 The angular strains γ_c at which sheared plate buckling occurs (Fig. 9.4.4.3.3), shall be calculated from the formula:

$$\gamma_c = \frac{1}{G\,t} c \left(\frac{\pi}{b_1}\right)^2 \sqrt[4]{D_{11} \cdot D_{22}} \qquad (9.4.4.3.3)$$

where:

G – substitute value of rigidity module of plate calculated from the formula 9.4.3.7-3;

t, D_{11}, D_{22} – defined in 9.4.4.3.2;
c – coefficient of values given in Table 9.4.4.3.3, depending on α and β;
α, β – defined in 9.4.4.3.2;
$b_1 = b$ – when $\alpha \geq 1.0$;
$b_1 = a$ – when $\alpha < 1.0$;
a, b – defined in Fig. 9.4.4.3.3.

Table 9.4.4.3.3
Values of coefficient *c*

Values β	Values α 1)									
	≤ 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.0	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.2	4.5	4.9
0.4	4.2	4.3	4.5	4.8	4.9	5.1	5.5	6.0	6.3	6.9
0.8	5.1	5.2	5.4	5.6	6.0	6.2	6.8	7.2	7.9	8.3
1.0	5.3	5.5	5.6	6.0	6.3	6.8	7.2	7.9	8.5	9.2
1.2	5.9	6.0	6.2	6.5	6.9	7.3	8.0	8.6	9.2	10.2
1.6	6.5	6.7	7.0	7.2	7.8	8.2	9.0	9.9	10.9	12.0
2.0	7.1	7.3	7.8	8.1	8.7	9.3	10.2	11.1	12.3	13.6
2.4	7.9	8.0	8.3	9.0	9.7	10.4	11.5	12.7	14.0	15.3
≥ 2.8	8.3	8.7	9.0	9.7	10.3	11.3	12.6	13.9	15.3	17.0

Notes:

1) If $\alpha = \frac{a}{b}\sqrt[4]{\frac{D_{22}}{D_{11}}} < 1.0$, then $1/\alpha$.shall be taken instead of α.

2) For intermediate values of α and β, c shall be determined by linear interpolation.

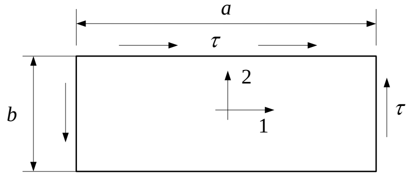


Fig. 9.4.4.3.3.Shearing the plate

9.4.4.3.4 Values ε_c defined in 9.4.4.3.2 and γ_c defined in 9.4.4.3.3 shall be at least 3 times greater than strains ε and γ due to design loads.

9.4.4.3.5 In the conditions of combined plate compression in directions ”1” and ”2” and possible shearing (Fig. 9.4.4.3.5), the below condition shall be fulfilled:

$$\left|\frac{\varepsilon_1}{\varepsilon_{c1}}\right| + \left|\frac{\varepsilon_2}{\varepsilon_{c2}}\right| + \left|\frac{\gamma}{\gamma_c}\right| \leq \frac{1}{C} \qquad (9.4.4.3.5)$$

where:
ε_1, ε_2, γ – values of strains due to design loads;
ε_{c1}, ε_{c2} – values ε_c calculated from formula 9.4.4.3.2-1, for unidirectional compression in directions ”1” and ”2” (Fig. 9.4.4.3.5);
γ_c – to be calculated from formula 9.4.4.3.3;
$C = 3.0$ – safety coefficient.

For tensile σ_1 or σ_2 (Fig. 9.4.4.3.5) then $\varepsilon_1 = 0$ or $\varepsilon_2 = 0$ shall be taken in formula 9.4.4.3.5.

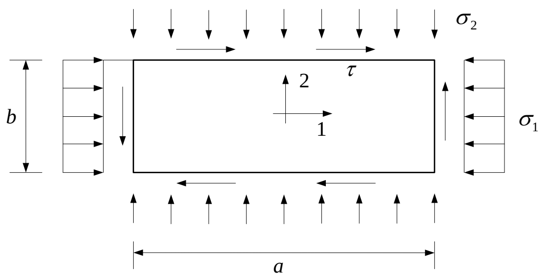


Fig. 9.4.4.3.5. Two-axial compression combined with shearing

9.4.5 Rigidity and strength of plating stiffeners

9.4.5.1 Application

The requirements of 9.4.5 apply to the assessment of rigidity and strength of stiffeners supporting plating loaded with pressure or subject to concentrated loads due to cargo and stores weight or the load of ship equipment items.

9.4.5.2 Assumptions and recommendations

It is assumed that the plating stiffeners are constructed as a web (or 2 webs in case of trapezoid stiffeners) connected with plating, which balances transverse load (shear forces) in the form of shear stresses, and connected with flange web (webs), which balances internal bending moments by normal stresses (along stiffener axis).

It is recommended that stiffeners should have symmetrical construction against the axis perpendicular to the supported plating, to avoid transverse torsion and bending of flange.

9.4.5.3 Calculation models and rigidity and strength criteria

It is assumed that stiffening with the effective width of plating (see 9.4.5.4) is considered as the cross-section of a beam having bending and shear rigidity defined in 9.4.5.5.

Maximum values of bending moment and shear force in a beam are calculated (see 9.4.5.6) and subsequently normal and shear strains (9.4.5.7) used in the strength assessment of individual layers of face plate, web and plating strake are determined – by methods applied in 9.4.3 for laminate plates.

Maximum deflections of beams are determined according to requirements of 9.4.5.8.

Stiffeners strength and rigidity criteria specified in 9.4.5.9 shall be complied with.

9.4.5.4 Plating effective flange

The breadth b_e of effective flange of plating shall be assumed as equal to lower value of the below two values:

$$b_{e1} = b_w + \frac{1}{6} l \qquad (9.4.5.4\text{-}1)$$

$$b_{e2} = \frac{1}{2}(s_1 + s_2) + b_w \qquad (9.4.5.4\text{-}2)$$

where:

b_w – defined in Fig. 9.4.5.4; for tea bar or angle bar stiffeners, $b_w = 0$ shall be assumed;

l – stiffener span, i.e. distance between cross-sections supported by adjacent primary supporting members, etc.

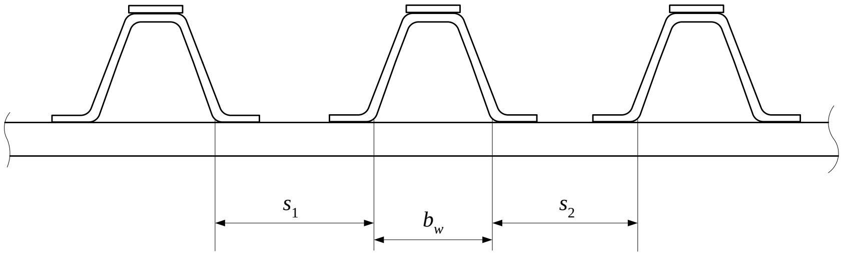


Fig. 9.4.5.4

9.4.5.5 Bending and shear stiffeness

Substitute Young's modules E_{wi} shall be determined along the axis of stiffening particular parts of then stiffener cross-sections (plating effective flange, web/webs, face plate) by considering them as plates and by using formulae given in 9.4.3.7. The alternative values G_{xyi} of webs shall be determined similarly (formula 9.4.3.7-3).

Subsequently, distance z_n of neutral axis of stiffener cross-section to the external edge of plating (Fig. 9.4.5.5) shall be calculated from the formula:

$$z_n = \sum E_{wi}\, A_i\, z_i / \left(\sum E_{wi}\, A_i\right) \qquad (9.4.5.5\text{-}1)$$

where:
A_i – cross-sectional area of i part of cross-section;
z_i – distance of gravity centre of i part of cross-section to external edge of plating.

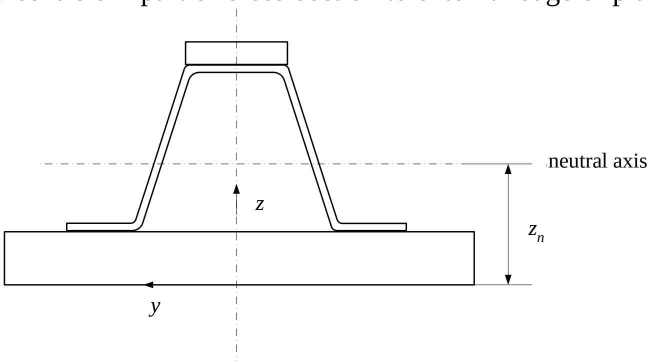


Fig. 9.4.5.5

Bending stiffness EI of beam (needed for estimating the beam deflection) shall be calculated from the formula:

$$EI = \sum E_{wi}\left(I_{wi} + A_i\, e_i^2\right) \qquad (9.4.5.5\text{-}2)$$

where:
E_{wi}, A_i – as in the equation 9.4.5.5-1;
e_i – distance (along z axis – Fig. 9.4.5.5) of gravity centre of i part of beam cross-section to neutral axis of the cross-section;
I_{wi} – own inertia moment of i part of plating.

The stiffness on the beam cross-section wall shall be calculated from the formula:

$$GA = \sum G_{xyi}\, t_i\, h_i \qquad (9.4.5.5\text{-}3)$$

where:
G_{xyi} – as defined above;
t_i – thickness of web i;
h_i – height of web i, measured transversely to plating.

9.4.5.6 Maximum values of bending moment and shear force

The maximum values of bending moment in the stiffener supporting the plating loaded with pressure shall be calculated from the formula:

$$M_{\max} = \frac{psl^2}{c_m} r_\kappa \qquad (9.4.5.6\text{-}1)$$

where:

p – pressure in the middle of span „*l*” of beam;
l – the beam span (distance between supported cross-sections);
s – breadth of supported plating strake;
$r_\kappa = 1.15 - 5\frac{h}{l}$, however, not less than 0.65;
h – stiffener deflection off the straight line (Fig. 9.4.5.6);
c_m – coefficient with values:

12 – for continuous horizontal stiffeners loaded with pressure *p* = const along the whole length;
10 – for vertical stiffeners connected by ends with other stiffeners (e.g. side frame connected with transverse deck beams);
8 – for stiffeners with simply supported ends and *p* = const along the whole length.

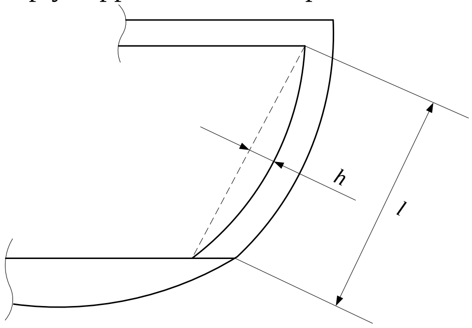


Fig. 9.4.5.6

For other loads and ends supports, the values of $M_{\max}$ shall be calculated directly by mechanical methods or by FEM.

The maximum value of shear force in the stiffener supporting plating loaded with pressure shall be calculated from the formula:

$$Q_{\max} = \frac{psl}{2} c_q \qquad (9.4.5.6\text{-}2)$$

where:

p, *s*, *l* – as in equation 9.4.5.6-1
c_q – coefficient with the following values:

1 – where *p* = const along the beam and both ends are similarly supported;
1.25 – where one end of beam is fixed and the other simply supported (*p* = const along the whole beam length);
0.75 – for the case as above and the simply supported end.

For other loads and ends supports, the values of $Q_{\max}$ shall be calculated directly by mechanical methods or by FEM.

9.4.5.7 Normal strains (along the beam axis), due to internal moment $M_{\max}$ (see 9.4.5.6) shall be calculated from the formula:

$$\varepsilon = \frac{M_{\max}}{EI} z \qquad (9.4.5.7\text{-}1)$$

where:

EI – to be calculated from formula 9.4.5.5-2;
z – the distance to neutral axis whose position is calculated from formula 9.4.5.5-1.

After calculation of ε, strains ε_1, ε_2, γ_{12} shall be determined for individual layers constituting individual elements of the beam (the co-ordinate system „12" is shown in Fig. 9.4.2.2, and the x axis on the Figure is led along the beam axis) from the formulae:

$$\varepsilon_1 = \cos^2\theta \cdot \varepsilon \qquad (9.4.5.7\text{-}2)$$

$$\varepsilon_2 = \sin^2\theta \cdot \varepsilon$$

$$\gamma_{12} = -2\sin\theta\cos\theta \cdot \varepsilon$$

where:

α – the angle shown in Fig. 9.4.2.2.

Subsequently, stresses σ_1, σ_2, τ_{12} may be determined (in the co-ordinate system „12" – in Fig. 9.4.2.2) by using formula 9.4.2.8-1.

The angle of rigidity deformation γ_{xy} of the beam web layers (the x axis is led along the beam axis) shall be determined from the formula:

$$\gamma_{xy} = \frac{Q_{max}}{GA} \qquad (9.4.5.7\text{-}3)$$

where:

Q_{max} – to be calculated acc. to 9.4.5.6;
GA – defined by formula 9.4.5.5-2.

Strains ε_1, ε_2, γ_{12} in the layers constituting the webs (Fig. 9.4.2.2) shall be calculated from the formula:

$$\varepsilon_1 = \sin\theta\cos\theta\,\gamma_{xy} \qquad (9.4.5.7\text{-}4)$$

$$\varepsilon_2 = -\sin\theta\cos\theta\,\gamma_{xy}$$

$$\gamma_{12} = \left(\cos^2\theta - \sin^2\theta\right)\gamma_{xy}$$

Subsequently, stresses σ_1, σ_2, τ_{12} in the web layers, due to its shearing, may be determined using the formula 9.4.2.8-1.

The stresses shall be added to those stresses due to moment M acting in the same cross-section of the beam, where the shear force Q_{max} is acting.

9.4.5.8 Beam deflection

The maximum deflection value of the span of stiffener supporting plating loaded with pressure p = const along the whole stiffener length l shall be calculated from the formula:

$$f_{max} = \frac{psl^4}{384EI}c_f \qquad (9.4.5.8)$$

where:

p, s, l – as in equation 9.4.5.6-1;
EI – beam bending rigidity acc. to equation 9.4.5.5-2;
c_f – coefficient with values:
- 1 – for beam ends fixed;
- 5 – for beam ends simply supported;
- 2.1 – for one beam end fixed and the other simply supported.

For other loads and ends supports, the values of f_{max} shall be calculated by mechanical methods or by FEM.

9.4.5.9 Rigidity and strength criteria for plating stiffeners

The maximum value of deflection f_{max} calculated according to 9.4.5.8 shall fulfil the below condition:

$$\frac{f_{max}}{l} \le 0.005 \qquad (9.4.5.9\text{-}1)$$

where:

l – stiffener span – as in formula 9.4.5.6-1.

PRS shall separately consider the possibility of applying higher values of f_{max}/l than the above, depending on the ship hull structure specific features.

The same level of permissible values of strains ε_1, ε_2, γ_{12} or stresses σ_1, σ_2, τ_{12} is obligatory, in coordinate systems „12" of particular layers of elements forming stiffener cross-section (see co-ordinate system „12" in Fig. 9.4.2.2) as for plating plates, defined in 9.4.3.12.3.

For longitudinal stiffeners, summarized values of ε_1, ε_2, γ_{12} or σ_1, σ_2, τ_{12} due to local bending, bending of primary supporting members with stiffeners within their effective flanges (acc. to 9.4.7) and hull general bending (acc. to 9.4.9) by moment $M = M_s + 0.59M_w$ (M_s – still water bending moment; M_w – wave bending moment) shall be considered.

For stiffeners of watertight bulkheads, during emergency flooding of watertight compartment, the level of permissible strains/stresses may be by 20% greater than in normal service conditions.

9.4.6 Buckling of plating stiffeners

9.4.6.1 Methods of buckling analysis of plating stiffeners and criteria to be fulfilled are specified in 9.4.8.

9.4.7 Rigidity and strength of primary supporting members

9.4.7.1 Application

The requirements of 9.4.7 apply to the rigidity and strength assessment of hull primary supporting members (i.e. strong elements of structure supporting plating stiffeners).

Similar assumptions and recommendations as in 9.4.5.2, concerning plating stiffeners, apply.

9.4.7.2 Calculation models

Calculations of strains and stresses in primary supporting members shall be performed by mechanical methods or FEM.

If beam models are applied (continuous beams, grids, flat frames or three-dimensional frames), the bending rigidity (*EI*) and shear rigidity (*GA*) shall be determined similar to the case of plating stiffeners (9.4.5.5).

The breadth of effective flange of the primary supporting member shall be determined as in the case of plating stiffeners (formulae 9.4.5.4-1 and 9.4.5.4-2) assuming:

s_1, s_2 – primary supporting member distance to neighboring members, bulkheads, sides, deck, etc.

l – distance between the member supporting points (e.g. for bottom centre girder, distance between transverse bulkheads).

During FEM calculations, it is recommended to apply calculation model with special shell elements used normally to laminate plates. Such calculations are subject to special consideration by PRS.

9.4.7.3 Strains and stresses in primary supporting members

The strains and stresses within individual laminate layers forming elements of primary supporting members structure (webs, face plate with unidirectional reinforcement, etc.) shall be calculated similar to plating stiffeners, i.e. acc. to 9.4.5.7.

9.4.7.4 Rigidity and strength criteria for primary supporting members

Rigidity criterium given in 9.4.5.9 (applicable to plating stiffeners) shall apply. For primary supporting members, the span l shall be determined as specified in 9.4.7.3.

PRS shall separately consider the possibility of application of higher values of f_{max}/l than specified above, depending on the hull structure features.

The method of the assessment of members strength and criteria similar to the case of plating stiffeners (see 9.4.5.9) applies.

For longitudinal stiffeners (transmitting normal stresses due to hull general bending), combined values ε_1, ε_2, γ_{12} (or σ_1, σ_2, τ_{12} – see 9.4.5.9) due to zone bending of primary supporting members and hull general bending (acc. to 9.4.9) by moment $M = M_s + 0.59M_w$ (M_s still water bending moment; M_w – wave bending moment), shall be considered.

For watertight compartment emergency flooding conditions, the level of permissible strains/stresses of primary supporting members of watertight bulkheads may be by 20% greater than in normal service conditions.

9.4.8 Buckling of plating stiffeners, primary supporting members and deck supports

9.4.8.1 General

9.4.8.1.1 The plating stiffeners, primary supporting members and pillars shall comply with specified in this paragraph criteria for (global) buckling strength in compression conditions.

Face plates and webs of primary supporting members shall comply with strength criteria as regards their local buckling due to compressive and shear stresses.

9.4.8.2 Lateral buckling

9.4.8.2.1 For stiffener or primary supporting member, the critical value of compressive force (resulting in lateral buckling) shall be calculated form the formula:

$$P_E = \frac{\pi^2 EI}{l^2\left(1+\dfrac{\pi^2 EI}{l^2 GA}\right)} \qquad (9.4.8.2.1)$$

where:

EI – bending rigidity, calculated according to formula 9.4.5.5-2;
GA – shearing rigidity, calculated according to formula 9.4.5.5-3;
l – beam span (distance between supported cross-sections).

9.4.8.2.2 The axial force transmitted by stiffeners or primary supporting member, including plating effective flange (see 9.4.5.4), calculated for design values of loads defined in 9.3.5, shall be at least three times less than force P_E defined in 9.4.8.2.1.

9.4.8.3 Torsional buckling

9.4.8.3.1 The use of the tripping brackets of primary supporting members will be separately considered by PRS.

9.4.8.4 Local buckling of face plate or web

9.4.8.4.1 The assessment of local buckling strength of face plates and webs of plating stiffeners or primary supporting members shall be performed using methods and criteria for plates buckling, specified in 9.4.4.

In the case of webs, the shear shall be considered.

9.4.8.5 Buckling of pillars

9.4.8.5.1 For pillars made of laminate, the requirements similar to specified in 9.4.8.2 shall be applied.

For circular or rectangular section pipe pillars, zero may be placed instead of $\pi^2 EI/\left(l^2 GA\right)$ in formula 9.4.8.2.

9.4.8.5.2 Where steel or aluminium pillars are used, the requirements for buckling of compressed pillars defined in Chapter 13 of the *Rules for the Classification and Construction of Sea-going Ships* shall be complied with.

9.4.9 General strength of hull

9.4.9.1 Application

The requirements of 9.4.9 apply to the assessment of general bending ship hull strength.

9.4.9.2 Bending moments and transverse forces

The design values of bending moment M and transverse (shear) force shall be determined according to the requirements of 9.3.6 as summarized still water and waving components (M_s; M_w; Q_s; Q_w).

9.4.9.3 Calculation method

9.4.9.3.1 The hull is treated as a beam in which internal bending model M and internal transverse force Q is found.

9.4.9.3.2 The internal moment M results in normal stresses σ along ship length. The stresses are transmitted by continuous longitudinal supporting members (of bottom, sides, deck plating, longitudinal plating stiffeners, longitudinal primary supporting members). The method of considering openings in hull structure members is similar to that described in Chapter 15 of *Part II – Hull* of the *Rules for the Classification and Construction of Sea-going Ships*.

The effect of superstructures/deckhouses on general bending hull strength will be considered separately by PRS, considering specific features of hull structure.

9.4.9.3.3 The method of determining position of bending and bending rigidity neutral axis EI of the whole hull is similar to the method used in calculation of plating stiffeners (see 9.4.5.5).

Symbols E_{wi}, A_i, z_i met there shall in this case refer to particular parts of continuous primary supporting members of the whole cross-section, i.e. plating, stiffener and webs and face plates of longitudinal primary supporting members.

9.4.9.3.4 Normal strain ε shall be calculated (along hull length) by using formula 9.4.5.7-1 ($M = M_s + M_w$ to be placed instead of $M_{\max}$), and subsequently strains ε_1, ε_2, γ_{12} within particular layers of hull transverse section members (formula 9.4.5.7-2).

Subsequently, stresses σ_1, σ_2, τ_{12} may be determined using formula 9.4.2.8-1.

9.4.9.3.5 The angle of rigidity deformation of sides/inner sides in local co-ordinate system xz, where the x axis is led along hull axis, while the z axis is tangential to particular plates of sides, shall be calculated from the formula:

$$\gamma_{xz} = \frac{Q}{\sum A_i G_{xzi}} \qquad (9.4.9.3.5)$$

where:

$A_i = h_i \cdot G_{xzi}$;

h_i – plate height measured vertically;

t_i – plate thickness;

G_{xzi} – rigidity module of plate, calculated as G_{xy} acc. to formula 9.4.3.7-3.

9.4.9.3.6 The strains and stresses calculated according to the requirements of 9.4.9.3.4 for bending moment $M = M_s + M_w$, shall not exceed 33% of destructive values – similar to the case of plate strength, acc. to 9.4.3.12.3.

9.4.9.3.7 The strains and stresses in side/inner side plates corresponding to the angle of rigidity deformation γ_{xz} calculated acc. to 9.4.9.3.5, shall be not more than 33% of strains and stresses destructive for particular layers, calculated similar to the case of plating stiffener webs, i.e. acc. to 9.4.5.7, where the above value γ_{xz} shall be placed instead of γ_{xz}.

9.5 Ship motions

9.5.1 General

9.5.1.1 The present Chapter gives formulae for determining motions (displacements, velocities and accelerations) of ships of length $L \geq 24$ m in sea-going conditions during their normal service.

9.5.1.2 The ship motions are the values for which probability of exceeding is 10^{-8}.

9.5.1.3 For ships of restricted service, the motions may be reduced by:
- by 10% for service area **II**,
- by 30% for service area **III**,
- by 40% for service area corresponding to mark Class C,
- by 50% for service area corresponding to mark Class D.

In justified cases, PRS may determine other reduction of ship motions defined in this Chapter.

9.5.2 Definitions

9.5.2.1 Co-ordinate System

The co-ordinate system, as well as names of various ship motions in waves, are defined in Fig. 9.5.2.1.

9.5.2.2 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:

$$C_w = 0.0856 L_0 \qquad (9.5.2.2)$$

9.5.3 Amplitudes of ship motions

9.5.3.1 Heave amplitude

The heave amplitude may be determined from the following formula:

$$Z_A = 12 - 0.1T \text{ [m]} \qquad (9.5.3.1)$$

T – see 2.2.

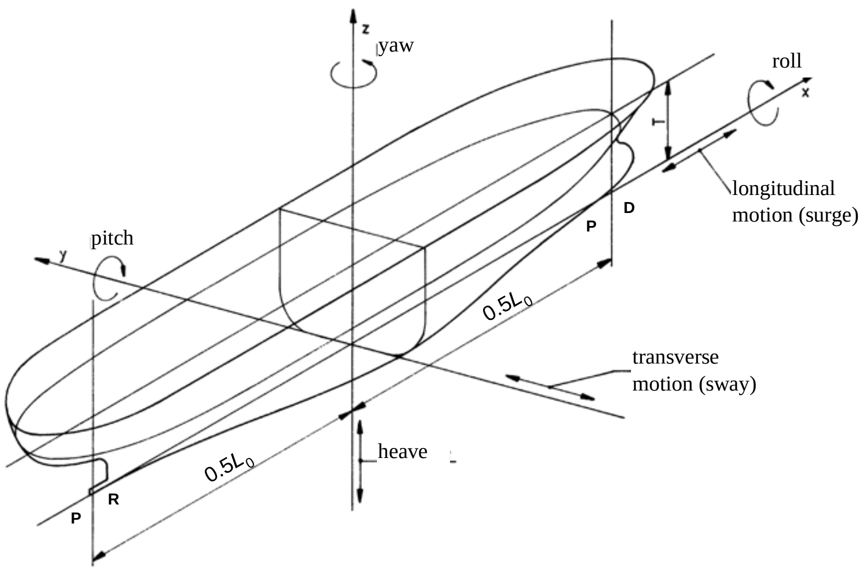


Fig. 9.5.2.1. Definition of co-ordinate system and names of ship motions in waves

9.5.3.2 Pitch amplitude

The pitch amplitude may be determined from the following formula:

$$\Theta_A = 4\left(1 - 4.5\frac{T}{L_0}\right)\frac{C_w}{L_0} \text{ [rad]} \qquad (9.5.3.2)$$

9.5.3.3 Roll amplitude

The roll amplitude (heel angle) may be determined from the below formula:

$$\Phi_A = 35 \frac{T}{B^2 + 50} \text{ [rad]} \tag{9.5.3.3}$$

9.5.3.4 Longitudinal motion (surge) amplitude

The longitudinal motion (surge) amplitude may be determined from the formula:

$$X_A = 8 \frac{1 - 0.03T}{1 - 0.036v} \text{ [m]} \tag{9.5.3.4}$$

v – ship speed, [knots].

9.5.3.5 Transverse motion (sway) amplitude

The transverse motion (sway) amplitude may be determined from the formula:

$$Y_A = 12 - 0.25T \text{ [m]} \tag{9.5.3.5}$$

9.5.3.6 Yaw amplitude

The yaw amplitude may be determined from the formula:

$$\Psi_A = 0{,}25\left(1 - 0{,}008 \frac{L_0 T}{B}\right) \text{ [rad]} \tag{9.5.3.6}$$

9.5.3.7 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:

$$S_A = \sqrt{(0.3Z_A)^2 + [(x + 0.05L_0)\Theta_A]^2 + [0.8y\Phi_A]^2}, \text{ [m]} \tag{9.5.3.7}$$

Z_A, Θ_A, Φ_A – see 9.5.3.1, 9.5.3.2 and 9.5.3.3;
x, y – co-ordinates of point P – see Fig. 9.5.2.1.

9.5.4 Resultant acceleration amplitudes

9.5.4.1 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 from the following formula:

$$a_v = (1 + 0.036v)^2 \frac{25}{L_0} \sqrt{Z_A^2 + [1.6(x + 0.05L_0)\Theta_A]^2 + [0.5y\Phi_A]^2}, \text{ [m/s}^2\text{]} \tag{9.5.4.1}$$

v = ship speed [knots];
Z_A, Θ_A, Φ_A – see 9.5.3.1, 9.5.3.2 and 9.5.3.3;
x, y – co-ordinates of point P – see Fig. 5.2.1.

9.5.4.2 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 from the following formula:

$$a_T = (1 + 0.036v)^2 \frac{25}{L_0} \sqrt{(0.8Y_A)^2 + [(x + 0.05L_0)\Psi_A]^2 + [(z - T)\Phi_A]^2}, \text{ [m/s}^2\text{]} \tag{9.5.4.2}$$

v = ship speed [knots];
Θ_A, Y_A, Ψ_A – see 9.5.3.2, 9.5.3.5 and 9.5.3.6;
x, z – co-ordinates of point P – see Fig. 9.5.2.1.

9.5.4.3 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 from the following formula:

$$a_L = (1+0.036v)^2 \frac{25}{L_0} \sqrt{(0.2\,X_A)^2 + [0.5y\,\Psi_A]^2 + [2(z-T)\Theta_A]^2}\ ,\ [\mathrm{m/s^2}] \qquad (9.5.4.3)$$

v = ship speed [knots];
Θ_A, X_A, Ψ_A – see 9.5.3.2, 9.5.3.4 and 9.5.3.6;
y, z – co-ordinates of point *P* – see Fig. 9.5.2.1.

9.5.4.4 Resultant acceleration in any direction

The resultant linear acceleration *a* of the ship's point *P* in any direction may be determined from ellipsoid (Fig. 9.5.4.4) with principal axes ($a_v + g$), a_T and a_L.
a_v, a_T and a_L – see 9.5.4.1, 9.5.4.2 and 9.5.4.3.
P(x, y, z) – point for which the accelerations are determined.

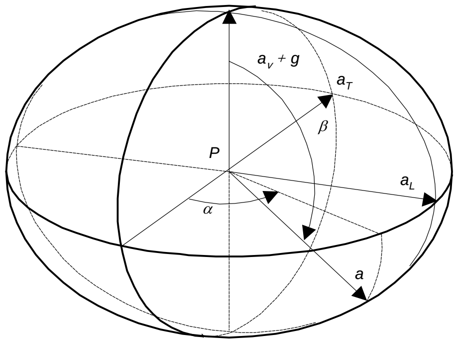


Fig. 9.5.4.4. Determining acceleration *a* of the ship's point *P* in any direction

10 FIRE PROTECTION

10.1 Passive fire protection covering: principles of use of combustible materials, insulation materials, non-combustible wall structures, fire division structures, separation of ship spaces

10.1.1 General

10.1.1.1 Use of laminates significantly influences the fire safety. Some applications do not ensure the safety to satisfactory degree, therefore any doubts will be resolved by PRS on the basis of Circular MSC.1/Circ.1455 or its further revisions.

10.1.1.2 PRS permits the use of design alternative solutions if it is proven that they ensure equivalent level of fire safety.

10.1.1.3 No individual passenger cabins are allowed onboard ships, only general use spaces are permitted.

10.1.1.4 The use of fuel of flash point below 60°C is forbidden.

10.1.2 Definitions

For the purpose of this *Publication*, the following definitions have been adopted:

– FTP Code – *the International Code for the Application of Fire Test Procedures*, as amended;
– Standard fire test – a test, with regard to fire structures, in which specimens of the relevant bulkheads or decks are exposed in a test furnace to temperatures corresponding approximately to the standard time-temperature curve, in accordance with the test method specified in the *FTP Code*;
– Non-combustible material – a material which neither burns nor gives off inflammable vapours in sufficient quantity for self-ignition when heated to 750 °C, this being determined in accordance with the *FTP Code*. Any other material is a combustible material.

– Low flame-spread material – means for materials used in structural fire protection the material of low flame-spread characteristics, this being determined in accordance with the *FTP Code*;
– Material resistant to flame propagation – material designated for structures and finishing surfaces of bulkheads, walls and ceilings formwork, of properties being determined in accordance with the *FTP Code*;
– Space (fire) category – a digital symbol being in accordance with descriptions in 10.1.6.3.6, indicating fire hazard of the given space and determining fire class of the space bounding divisions;
– Control stations – those spaces, in which the ship's radio or main navigating equipment[1)], or the emergency source of power[2)] and its switchboard are located, or where the fire recording or fire control equipment is centralized, or where other basic functions connected with safe service of the unit are operated, such as propulsion and stabilizing system control, broadcasting system operation, etc.;
– Continuously manned control station – control station which is continuously manned by a responsible member of the crew when the unit is in normal service;
– Machinery spaces – spaces where internal combustion engines or main propulsion engines, or those of total output above 110 kW, and generators, oil fuel units, major electrical machinery are located, as well as similar spaces with trunks leading thereto;
– Auxiliary machinery spaces – spaces where internal combustion engines of output up to 110 kW driving generators, pumps of sprinkler systems and water-spraying systems, fire pumps, bilge pumps, etc., oil filling stations, electric switchboards of total output above 800 kW and similar spaces are located and trunks to such spaces;
– Auxiliary machinery spaces of small or of no fire hazard – spaces such as refrigerating spaces, stabilizing, ventilating and air conditioning machinery spaces, spaces where electrical switchboards of up to 800 kW are located or similar spaces and trunks to such spaces;
– Service spaces – isolated spaces used as pantries containing dish heating appliances (without cooking appliances with uncovered heating surfaces), lockers, shops, stores and enclosed luggage lockers. Such spaces without cooking appliances may contain:
  .1 coffee automats, toasters, dish washers, microwave ovens, water heaters and similar appliances each of them with a maximum power of 5 kW;
  .2 electrically heated cooking plates and hot plates for keeping food warm each of them with a maximum power of 5 kW and surface temperature not above 150 °C.
– A class divisions – fire-resisting divisions formed by bulkheads, walls or decks which comply with the following criteria:
  .1 they are constructed of steel or other equivalent material,
  .2 they are suitably stiffened,
  .3 they are insulated with approved non-combustible materials such that the average temperature of the unexposed side will not rise more than 140°C above the original temperature, nor will the temperature at any one point, including any joint, rise more than 180°C above the original temperature, within at least the time listed below:
  Class A-60 – 60 min,
  Class A-0 – 0 min;
  .4 they are so constructed as to be capable of preventing the passage of smoke and flame to the end of the one-hour standard fire test;
  .5 a prototype bulkhead or deck forming A class division has been satisfactorily tested in accordance with the *FTP Code* requirements;

10.1.2.1 Fire-resisting divisions – divisions formed by bulkheads or decks, made of non-combustible or flame propagation resistant materials, which by the properties of used insulation or by fire-resistance of core material comply with the following criteria:

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1) The main navigational equipment includes, in particular, the unit control system, compass, radar and bearings.
2) Accumulator batteries, regardless of their capacity:
  .1 for power supply from black-out till start of emergency generator,
  .2 used as reserve source of energy to radiotelegraph installation,
  .3 batteries for start of emergency generator, and
  .4 batteries generally regarded as emergency source of power.

.1 they are suitably stiffened and where required maintain ability to transmit design loads for the whole period of fire protection;

.2 they are so constructed as to be capable of preventing the passage of smoke and flame to the end of the time of fire protection;

.3 they are insulated with approved non-combustible materials such that the average temperature of the unexposed side will not rise more than 140°C above the original temperature, nor will the temperature at any one point, including any joint, rise more than 180 °C above the original temperature, within at least the relevant time of fire protection;

.4 a prototype wall or deck structure forming A class division has been satisfactorily tested in accordance with the *FTP Code* requirements.

10.1.3 Scope of survey

10.1.3.1 During the ship construction, the survey covers fire protection structures, application of other materials and products and structural arrangements whose documentation is subject to consideration and approval.

10.1.4 Classification documentation

10.1.4.1 Prior to construction commencement, the following documentation of structural fire protection shall be submitted to PRS for consideration:

– Plan of structural fire protection,
– Plan of doors,
– Plan of windows,
– Plan of insulation,
– Plan of ship spaces equipment with required certificates,
– Plan of low-location lighting and designation of escape routes,
– List of required certificates for materials/components/structures used in fire divisions

10.1.5 Ignition hazard

10.1.5.1 It is recommended to use appropriate measures to prevent ignition of combustible materials or liquids, i.e. the use of materials of reduced combustibility, control of combustible liquid leakages and collecting their vapours, limiting the ignition sources and their separation from combustible materials and liquids, in order to reduce the ignition and fire hazard.

10.1.5.2 A separate space for smoking shall be provided onboard.

10.1.5.3 The use of open fire in cooking or dish warming appliances is forbidden.

10.1.5.4 Only electric cooking appliances of power output not exceeding 5 kW are allowed onboard.

10.1.5.5 The cooker hood shall be constructed of non-combustible material.

10.1.5.6 Heaters and cooking ovens shall be mounted with the use of non-combustible shield (plates), installed on walls and decks located in way of the heater.

10.1.5.7 No deep-fat cooking equipment shall be installed in galleys.

10.1.5.8 Decorative veneers of furniture and doors in public spaces, crew spaces and control stations shall have low flame-spread properties.

10.1.5.9 External surfaces of decks, walls and ceilings in public spaces, service spaces, crew spaces and control stations and surfaces of inaccessible spaces shall have low flame-spread properties.

10.1.6 Fire hazard

10.1.6.1 The use of combustible materials shall be restricted.

10.1.6.2 The independent tanks for lubrication oils and fuel oil in machinery space shall be made of steel.

10.1.6.3 The furniture structure shall be made of non-combustible materials of low flame-spread materials.

10.1.6.4 The insulating materials used in machinery spaces, accommodation spaces and service spaces and in control stations shall be non-combustible. In spaces where oil products may be located, the insulation coverings shall be impervious to such products and their vapours.

10.1.6.5 Waste and rubbish containers shall be made of non-combustible materials, able to be closed and without openings.

10.1.6.6 Each storeroom area shall be not more than 4 m^2.

10.1.6.7 The ventilation systems shall be capable of cutting off air inflow to machinery space and galley.

10.1.7 Fume and toxic substances creation hazard

10.1.7.1 Paints, varnishes and other finishing materials used on exposed surfaces inside accommodation, service spaces, control stations and in enclosed staircases may not emit excessive amounts of fume and toxic substances, this being determined in accordance with the *FTP Code.*

10.1.7.2 Furniture upholstering and curtain materials shall not emit excessive amounts of fume and toxic substances when burning.

10.1.8 Fighting fume spreading

10.1.8.1 Appropriate measures shall be applied to control fume spreading in control stations, machinery spaces and covered spaces.

10.1.8.2 In public spaces, crew and service spaces, control stations, corridors and staircases, the enclosed air spaces behind ceilings, linings or coverings shall be properly divided by fitting partitions preventing passage of air, spaced by not more than 14 m.

10.1.8.3 Machinery spaces and corridors shall be provided with gas-tight doors fitted with self-closing devices.

10.1.9 Fire containment

10.1.9.1 A ship shall be divided into spaces restricted by structural divisions, ensuring thermal and acoustic insulation.

10.1.9.2 Each fire, thermal and acoustic insulation material mounted on the divisions shall be non-combustible or flame propagation resistant.

10.1.9.3 Divisions (decks and bulkheads) shall have fire resistance complying with the requirements of Table 10.1-1 or equivalent.

10.1.9.4 The structure of doors and door frames, together with the devices securing them in closing position, window frames being closures of openings in fire-resistant divisions, as well as pipings, electric cables, ventilation ducts, etc. penetrating the divisions, shall ensure fire resistance and the resistance to flame and smoke permeability equivalent to that of divisions in which they are fitted. This shall be determined in accordance with the *FTP Code*.

10.1.9.5 For the purpose of classification of rooms or spaces given in Table 10.1-1, as regards fire hazard, the following division into groups is adopted:

.1 Spaces of high fire risk, marked with letter (A) in tables:
- machinery spaces,
- trunks to the above spaces.

.2 Spaces of moderate fire risk, marked with letter (B) in tables:
- auxiliary machinery spaces,
- crew spaces with sleeping places,
- service spaces,
- trunks to the above spaces.

.3 Spaces of low fire risk, marked with letter (C) in tables:
- auxiliary machinery spaces (of low or none fire risk),
- public spaces,
- tanks, voids and spaces of low fire hazard or without fire hazard,
- corridors in passenger spaces and close to stair cases,
- crew spaces other than those mentioned in .2,
- trunks to the above spaces.

.4 Control stations (including safety centre[1]), marked with letter (D) in tables:

.5 Embarkation stations and exterior escape routes, marked with letter (E) in tables:
- external stairways and open decks used as escape routes,
- assembly stations, internal and external,
- open deck spaces and enclosed promenades forming lifeboat and liferaft embarkation and lowering stations,
- ship's sides to the minimum draught waterline,
- sides of superstructures and deckhouses situated below or in the vicinity of liferafts and escape chutes;

.6 Open spaces, marked with letter (F) in tables:
- open spaces other than embarkation stations, external escape routes and control stations.

10.1.9.6 As regards classification of spaces given in 10.1.6.3.6, the following additional criteria apply:

.1 if the space has partial bulkheads dividing it into two, or more smaller areas being enclosed spaces, such enclosed spaces shall be bounded respectively with walls and decks in accordance with Table 10.1-1. If, however, the walls separating such spaces are open in at least 30%, then the space may be regarded as not separated;

.2 lockers/cabinets of floor area less than 2 m^2 may be accepted as a part of served space, provided they have ventilation open to the space and do not contain any materials or equipment posing fire hazard;

.3 if the space has specific properties of two or more groups of spaces, then the period of structural fire protection of the division shall be the highest for the group considered. For example, the period of structural fire protection for divisions of emergency units room shall have the highest value for the given space if the space is regarded as control station (D) and machinery space (A).

10.1.9.7 If the space is divided by a deck or wall, and each part has different fire system, then insulation required for the division of higher time of structural fire protection shall be spread on the length of at least 450 mm of the wall or deck with lower time of structural fire protection.

If the lower part of insulation must be cut off for the purpose of dewatering, the structure shall be performed in accordance with Fig. 7.3.6 of IMO Resolution MSC.222(82).

10.1.9.8 The below requirements apply to all units irrespective of their construction material. The times of structural fire protection of separating divisions and decks shall be such as shown in Table 10.1-1, and all the time values are based on the assumption of ensuring protection during evacuation, in accordance with paragraph 12.3.4.1, for 60 minutes. In no case, however, the time of structural fire protection may be less than 30 minutes.

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[1] A safety centre shall be located onboard each passenger ship, aimed at assisting safety management in emergency.
Details on relations among central control station, navigation bridge and safety centre are specified in MSC.1/ Circ.1368.
The safety centre shall be either a part of the ship navigation bridge or be located in separate room adjacent to the bridge with direct access thereto.

10.1.9.9 When using Table 10.1-1 it should be noted that designation of each space group is given more as general qualification than strict restriction. If any doubts arise as regards classification of spaces for the purpose of this Publication to determine respective standards of fire protection for divisions separating adjacent spaces, the group of spaces with the most restrictive values shall be applied.

10.1.9.10 Fire divisions, for which the time of structural fire protection amounts to 30 min. may be replaced by A-30 Class divisions, and those with 60 min. time of structural fire protection – by A-60 Class divisions.

Table 10.1-1
Times of structural fire protection for separating divisions and decks on passenger units

	A	B	C	D	E	F
A Areas of high fire risk	**60** *1* / **60** *1*	**30** / **60** *1*	*3* / **60** *1*	*2, 3* / **60** *1*	*3* / **60** *1*	– / **60** *1, 4, 5*
B Areas of moderate fire risk		**30** / **30**	*3* / **30**	*2, 3* / **60**	*3* / **30**	– / *3*
C Areas of low fire risk			*3* / *3*	*2, 3* / **30**	*3* / *3*	– / *3*
D Control stations				*2, 3* / *2, 3*	*3* / *2, 3*	– / *3*
E Embarkation stations and escape routes					*3* / *3*	– / *3*
F Open areas						– / –

Notes:
Bolded numbers on both sides of skew line present time (in minutes) of structural fire protection for fire resistant structure, required at respective side of the division[1)].

1 Upper surfaces of decks situated between spaces protected by fixed fire-extinguishing systems, need not be insulated.
2 The steering and control stands which at once serve as auxiliary machinery spaces, shall have 30 min. structural fire protection.
3 There are no requirements concerning structural fire protection, however, a smoke-proof division made of non-combustible materials or low flame-spread materials shall be installed.
4 There are no limitations for the rise of average temperature on the side not exposed to fire, for the whole time of fire protection.
5 The time of structural fire protection may be reduced to 0 minutes for those parts of open ro-ro spaces which are not major parts of load bearing structures and which are not accessible for passengers, and need not be entered by crew in any emergency.

10.1.10 Structure integrity

10.1.10.1 The ship structure integrity shall be maintained by preventing partial or whole destruction of structure members in result of reducing their thermal strength.

10.1.10.2 Applied materials shall prevent destruction of structure fire integrity.

10.1.10.3 Irrespective of the grade of basic materials used for divisions, the machinery room and its trunks shall be isolated from adjacent spaces by bulkheads and deck insulated by mineral wool used for insulating divisions up to Class A-60. The same method of insulating shall apply to sides in way of machinery room from the level of 300 mm below the lowest water line upwards.

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1) The non-bolded numbers mean the Note No.

10.1.10.4 The floor of the machinery room, if made from laminate, shall be covered with non-combustible material, e.g. steel plate.

10.1.10.5 Fuel tanks located in hull shall be isolated from other spaces by cofferdams.

10.2 Active fire protection covering: fixed fire extinguishing systems, fire signaling systems and portable fire-fighting equipment

10.2.1 General assumptions for fire-fighting

During fire onboard ship made of polymer composites, an early detection of fire and its extinguishing ”in the bud” constitutes the basic fire-fighting principle, to prevent rise of the temperature having effect on the ship structure.

Due to good insulation of polymer composite materials, the efficiency of fire-fighting depends mainly on the possibility of directing the fire-extinguishing medium onto the fire source.

Water is the most efficient medium for fighting fires of grp materials. When used in an early phase of fire, water quickly stops chemical reactions inside polymer composites and suppresses the fire.

During fire of polymer composite materials, cooling surfaces in fire is essential in order to lower the temperature and to avoid material re-ignition.

Gas fire-extinguishing systems are not recommended due to weak cooling capabilities.

10.2.2 Scope of survey

10.2.2.1 The following elements are subject to survey during ship construction or conversion: fixed fire-extinguishing systems, fire detection and signaling systems and other systems and arrangements within active fire protection, whose documentation is subject to consideration and approval.

10.2.2.2 Fixed fire-extinguishing systems or their components, the components of fire detection and signaling system, as specified in particular sub-chapters, and portable fire-fighting equipment shall be supplied together with *Type Approval Certificate* or other equivalent certificate.

10.2.2.3 Fire pumps, pumps supplying water spraying systems shall be supplied together with certificate of acceptance carried out under supervision of PRS surveyor.

10.2.2.4 Pressure vessels and bottles of gas fire-extinguishing systems, and CO_2 manifold shall be supplied together with pressure test and survey certificates issued by PRS.

10.2.2.5 Polymer composite materials used in the systems, such as pipes, connectors, handles, penetrations, etc. shall be supplied together with approval or survey certificate, in accordance with the requirements specified in sub-chapter 5.1.2.

10.2.2.6 During the ship service, fire-extinguishing systems and fire-protection equipment are subject to periodical technical surveys and attestation in accordance with PRS *Publication No. 29/I – Guidelines for Periodical Inspections of Fire-extinguishing Systems and Appliances Used on Ships*.

10.2.3 Classification documentation

Prior to the commencement of ship construction, the following technical documentation shall be submitted to the PRS Head Office for consideration and approval:

- **.1** plan of water fire main system, including the arrangement of fire pumps, pipelines and fire hydrants;
- **.2** plan of gas fire-extinguishing system of full capacity for engine room or an equivalent system;
- **.3** plan of fire detection and signaling system;
- **.4** plan of fire-fighting equipment arrangement;
- **.5** the fire control plan.

10.2.4 Fire Control Plan

Fire Control Plan, based on general plan of ship, shall be posted onboard all passenger ships, to include:

.1 the ship areas enclosed with fire divisions;
.2 control stations;
.3 the escape routes to life-saving means embarkation stations;
.4 the ship rooms and areas protected by the fire detection and signaling system and the distribution of manually operated call points;
.5 the ship rooms and areas protected by the fixed fire-extinguishing systems;
.6 the arrangement of fire-fighting equipment;
.7 the arrangement of closures of ventilation openings, fire dampers in ventilation ducts and positions of remote shutting off ventilating fans;
.8 the oil fuel and lubricating oil tanks located beyond double bottom, positions of remote closing of isolating valves of the tanks and positions of remote shutting off fuel and lubricating oil pumps;
.9 fire pumps, positions of their remote control and positions of remote control of main and emergency bilge pump;
.10 the emergency source of electrical energy (generating unit or accumulator battery) and emergency switchboard;
.11 the position of remote control of watertight doors and fire doors;
.12 the position of posting the *Fire Control Plan;*
.13 the passenger assembly stations.

Symbols used on the Plan shall be in accordance with IMO Resolution A.952(23) or obligatory ISO standards.

10.2.5 Fire protection of ship spaces

10.2.5.1 Passenger and crew spaces, service spaces and control stations

10.2.5.1.1 Passenger and crew spaces, service spaces, regarded as high and moderate fire risk areas, and other enclosed spaces located in public spaces, which are not continuously occupied by the crew, such as toilets, staircases and corridors, shall be fitted with fixed fire detecting and signaling system, with smoke detectors and manually operated call points, complying with 10.2.7, which allows to indicate fire position in the control station.

10.2.5.1.2 The manually operated call points shall be installed in public spaces, crew spaces, corridors and staircases. They shall be easily accessible in corridors on each deck at walking distance of not more than 20 m from any point of corridor. One call point shall be placed at each exit from the space and also at each exit from high fire risk areas.

10.2.5.1.3 The crew spaces, service spaces and control stations shall be provided with portable extinguishers, appropriate for fires of groups A and B. At least 5 extinguishers shall be placed onboard, so arranged to be ready for immediate use.

10.2.5.2 Machinery spaces

10.2.5.2.1 The machinery compartments regarded as areas of high and moderate fire risk shall be equipped with fixed fire detection and signaling system, with smoke detectors, complying with 10.2.7, which allows at normal operation of all machinery providing alarm on the place of the fire onset in the control station.

10.2.5.2.2 The machinery compartments for main propulsion shall be additionally equipped with detectors which react to the agent other than smoke, be supervised by CCTV cameras and monitored from the control station.

10.2.5.2.3 The machinery compartments regarded as high fire risk areas shall be equipped with fixed gas fire-extinguishing system complying with 10.2.6.3. The system shall be operated manually – locally and remotely from the control station.

10.2.5.2.4 Instead of fixed gas fire-extinguishing system, the water spraying system complying with applicable requirements of sub-chapter 3.2 of PRS *Publication 89/P – Guidelines for Design, Installation and Type Testing of Fixed Fire-extinguishing Systems Used Onboard Ships*, may be installed.

10.2.5.2.5 Portable extinguishers appropriate for extinguishing fires of group B shall be placed in machinery compartments.

10.2.5.3 Store-Rooms for Inflammable Liquids

10.2.5.3.1 A smoke detector of the fire detection and signaling system shall be installed in the store-room.

10.2.5.3.2 Store-rooms for inflammable liquids having floor area over 4 m^2 shall be equipped with the fixed gas fire-extinguishing system or another fire-extinguishing system ensuring equivalent protection, operated from outside the store-room.

10.2.5.3.3 A portable fire extinguisher, relevant for extinguishing fires of group B shall be placed at the entry to the store-room.

10.2.6 Fixed fire-extinguishing systems

10.2.6.1 General

10.2.6.1.1 Pipings made of metallic materials or of light metal alloys shall be used in fire-extinguishing systems. The steel pipings, except those made of stainless steel, shall be corrosion protected, and double-side galvanizing is recommended.

10.2.6.1.2 The use of pipes made of plastics/ polymer composites, approved in accordance with the requirements of Chapter 5, is permitted in water-based fire-extinguishing systems.

10.2.6.1.3 The method of connecting pipings, penetrations through decks/divisions separating the spaces and piping fixtures to hull structure, shall be in accordance with national/international standards applicable in shipbuilding.

10.2.6.1.4 Pressurized pipings are subject to pressure test after being mounted onboard, with test pressure of at least 1.25 of the working pressure.

10.2.6.1.5 The pressure vessels and bottles for the storage of extinguishing agent, used in fire-extinguishing systems, shall comply with the requirements of national/international standards applicable in shipbuilding.

10.2.6.2 Water fire main system

10.2.6.2.1 Each ship shall be equipped with the water fire main system consisting of the fire pumps, the water supply pipings, hydrant valves and fire hoses with nozzles.

10.2.6.2.2 At least 2 fire pumps supplied from independent energy sources shall be used onboard, one of them being treated as emergency fire pump. The capacity of each pump shall be not less than 2/3 of the required capacity of fire pumps, however, not less than 25 m^3/h. Each pump shall be capable of delivering water with appropriate pressure, in the amount sufficient for simultaneous operation of hydrants, in accordance with the requirement of 10.2.3.2.6.

10.2.6.2.3 The fire pumps shall be so arranged that in the event of fire in any one compartment all the fire pumps will not be put out of action.

10.2.6.2.4 Possibility of remote starting of one of fire pumps from the control station shall be ensured. A pump operation indicator shall be placed where the pump is remotely started.

10.2.6.2.5 An isolating valve intended for isolation of piping sections located in machinery compartment containing the main fire pump, from the other pipings of the system, shall be fitted outside the machinery compartment. The arrangement of the system pipings shall be such that when the isolating valve is closed the shipboard fire hydrants can be supplied with water from the emergency fire pump.

10.2.6.2.6 The number and position of hydrants shall be such that at least two jets of water not emanating from the same hydrant valve delivered by a single fire hose section may reach any accessible part of the ship, both inside the ship spaces and on the open decks.

10.2.6.2.7 One fire hydrant shall be located close to the entry to the machinery compartment. At least 2 fire hydrants shall be placed onboard ship.

10.2.6.2.8 Fire hoses shall be of non-perishable material and respectively 10 or 15 m in length, taking into account the ship's length.

10.2.6.2.9 Fire hoses with nozzles shall be stowed in hose boxes, located in conspicuous positions near the hydrant valves, ready for immediate use. All fire hoses located inside spaces shall be permanently connected to fire hydrants.

10.2.6.2.10 Each hydrant valve shall be provided with one fire hose.

10.2.6.2.11 Each fire hose shall be provided with a water nozzle of dual-purpose (jet and spray) type, with a valve that can close water flow.

10.2.6.2.12 Nozzle sizes 12 mm, 16 mm or 19 mm shall be used on ships. Where other fire-extinguishing systems are used – such as fog fire-extinguishing systems – lower diameter nozzles may be permitted.

10.2.6.2.13 In ships of more than 24 m in length, the water fire main system shall be kept permanently pressurized and shall be such as to ensure an effective jet of water immediately available from any hydrant onboard and to ensure the continuation of the output of water jet by automatic starting one required fire pump.

10.2.6.3 Gas fire-extinguishing system

The system shall comply with applicable requirements of the *Rules for the Classification and Construction of High-speed Craft*, Chapter 3.3, except that it is not required that the quantity of fire-extinguishing medium shall be sufficient to provide two independent discharges.

The gas equivalent fire-extinguishing system for machinery compartments with extinguishing agents such as: FM-200, FE-36, etc., shall be of an approved type, and shall comply with the requirements of the standards applicable in shipbuilding.

10.2.6.4 Fixed fire detection and fire alarm system

The system shall comply with applicable requirements of the *Rules for the Classification and Construction of High-speed Craft,* subchapter 4.1. The system shall provide the possibility of remote identification of each detector and each manually operated call point.

The elements of fixed fire detection and alarm systems, such as: control panel, indicating unit, detectors and manually operated call points, electric cables, power supply equipment and short circuit isolators shall be of an approved type and shall comply with the requirements of the standards applicable in shipbuilding.

10.2.7 Fire fighting equipment

10.2.7.1 General

10.2.7.1.1 The fire fighting equipment including: fire extinguishers, protective clothing, fire-fighter's outfit and fire blankets, shall be supplied together with a certificate confirming its applicability in fire-fighting onboard ships.

10.2.7.1.2 The fire-fighting equipment shall be placed in easily accessible places onboard, preferably at the entrance to the space and shall be appropriately marked by symbols used in fire protection onboard ships.

10.2.7.2 Portable extinguishers

10.2.7.2.1 The fire-extinguishers shall be of a type approved based on the guidelines specified in Resolution A.951(23) and PN-EN 3-7 Standard as appropriate for marine applications.

10.2.7.2.2 Each portable powder extinguisher and CO_2 extinguisher shall contain at least 5 kg of extinguishing medium, while the foam extinguisher and water fog extinguisher – at least 9 *l* of extinguishing agent solution or water. Total mass of the portable extinguisher may not exceed 20 kg.

10.2.7.2.3 The CO_2 extinguishers may be used exclusively in galleys and for extinguishing electrical appliances. Considering the life hazard to persons present in the space, the extinguisher size shall ensure that no more than 1 kg of CO_2 falls on 15 m^3 of the space where the extinguisher is stored or used.

10.2.7.2.4 The extinguishers shall be so distributed and fixed onboard that they are always easily accessible and ready for use in case of fire.

10.2.7.2.5 The use of water fog extinguishers is recommended due to possible cooling of polymer composite structures.

10.2.7.2.6 The number of spare fire-extinguishers shall be at least 50% of each type of fire-extinguishers placed onboard.

10.2.7.3 Fire-fighter's outfit

Passenger ships carrying more than 100 passengers shall have onboard at least 2 sets of fire-fighter's outfit, complying with the requirements of *the Rules for the Classification and Construction of High-speed Craft*, subchapter 5.3.6.

11 VENTILATION

11.1 The requirements for ventilation systems are given in 22.3.4.1 of the *Rules for the Classification and Construction of Sea-going Ships, Part VI – Machinery Installations and Refrigerating Plants*.

11.2 Instead of ventilation ducts penetrations (steel sleeves), mounted in fire-proof divisions or in A Class divisions, required in 11.2.6 and 11.2.7 of *Part VI – Machinery Installations and Refrigerating Plants* of the *Rules for the Classification and Construction of Sea-going Ships*, other equivalent arrangements/structures are permitted, provided that they are subject to tests this being determined in accordance with the *FTP Code* (see 10.1.6.4.5 of this *Publication*).

12 ESCAPE ROUTES, ASSEMBLY AND EMBARKATION STATIONS, ESCAPE MEANS AND LIFE-SAVING APPLIANCES

12.1 General

12.1.1 Passengers and crew shall have the possibility of safe passage to assembly station in the case of fire.

12.1.2 Passengers and crew shall have the possibility of safe evacuation from the ship if necessary.

12.2 Functional requirements

12.2.1 The onboard escape routes shall be designed which lead from accommodation, service spaces and control stations, possibly straight and of adequate width.

12.2.2 The area of assembly stations shall be adjusted to the number of passengers to be served by the station. Open deck assembly stations shall preferably be arranged.

12.3 Design solutions

12.3.1 Escape routes

12.3.1.1 Design of corridors, stairs and ladders shall ensure the possibility of escape to an open deck from each accommodation room and each room permanently occupied by the crew.

12.3.1.2 Two means of escape, as widely separated as possible, shall be provided from all accommodation and service areas on each deck, where practicable considering the size of rooms and crew number.

12.3.1.3 Two means of escape, as widely separated as possible, shall be provided from each machinery compartment, one of them being an emergency exit. If the skylight is arranged as an emergency exit it shall be possible to open it from both sides.

12.3.1.4 PRS may allow for the possibility of one escape route from the accommodation area or machinery space, considering the size and layout of the spaces (e.g. when the walking distance from the most remote place in the room to the exit does not exceed 5 m).

12.3.1.5 The escape routes width should not decrease towards assembly/embarkation stations, nor be impeded by furniture or equipment items.

12.3.1.6 Doors located in the escape route shall open in the direction of evacuation.

12.3.1.7 The width of corridors, doors and stairways which form part of the evacuation paths shall amount to at least 900 mm. This width may be reduced to 600 mm for corridors, doorways and stairways serving space where persons are not normally employed.

12.3.1.8 Special category spaces used for stowage of motor vehicles shall be provided with walkways having a width of at least 600 mm leading to a safe means of escape.

12.3.1.9 Adequate notices shall be provided to direct passengers to exits

12.3.2 Assembly stations

12.3.2.1 A minimum of 0.35 m^2 of assembly station area shall be provided for each passenger.

12.3.2.2 If provision of assembly stations on the open deck to all passengers is not practicable, then one of passenger spaces shall be divided by a longitudinal bulkhead (e.g. FRD) into two rooms, so that one of them could serve as the assembly station.

12.3.3 Embarkation stations

12.3.3.1 The embarkation stations shall be arranged possibly far away from the engine room.

12.3.3.2 At least three possible embarkation stations on each side shall be provided.

12.3.3.3 For passenger ships carrying more than 100 passengers, application of MES as a means of evacuation is recommended.

12.3.4 Evacuation time and drill

12.3.4.1 The time of evacuation shall be defined in accordance with paragraph of 4.8.1 of *the International Code of Safety for High Speed Craft 2000.*

12.3.4.2 An evacuation drill shall be performed onboard ship in accordance with paragraphs of 4.8.2 to 4.8.11 of *the International Code of Safety for High Speed Craft 2000.*

13 SURVEYS

13.1 Surveys of structural fire protection items

13.1.1 Annual survey

13.1.1.1 Fire divisions and fire-protection structures – required scope of activities:

.1 external examinations of fire divisions: checking the condition of insulation (if any), integrity of division plates (including lack of laminations) – if they are fabricated of ready-made plates, the tightness of piping, ventilation ducts and cables penetrations, the tightness of closures of openings in the divisions fitted in:
- accommodation spaces, service spaces and control stations
- machinery spaces;

.2 external examination of fire protection constructions to verify that no alterations have been made, including: the enclosures of stairways and lifts, ventilation systems, windows and side-scuttles and no combustible materials have been used

.3 external examinations of draught stops

13.1.1.2 Fire doors – required scope of activities:

.1 external examinations of all fire doors;

.2 operation test of all self-closing fire doors (hinged and sliding doors);

.3 operation test of remote release of all fire doors designed to be permanently kept open, from control station and their closing from a position at both sides of the door;

.4 operation test of closure indication of all doors at the fire door indicator panel in control station;

.5 operation test of release mechanism allowing to automatically close the door in the event of disruption of the control system or central power supply.

13.1.1.3 Escape routes – required scope of activities:

.1 examination of internal and external means of escape leading to liferaft and life boat embarkation stations: verification that ladders/steps/handrails/floor plates on escape routes are made of steel and they are properly secured, and that escape routes are not impeded by furniture, cleaning gear and other obstacles:
- in accommodation spaces, service spaces and control stations
- in machinery spaces
- on open decks;

.2 examination of marking and lighting (supplied from the emergency source of power) of escape routes, emergency exits and assembly stations;

.3 examination of overhead hatches which form escape routes from spaces
- checking whether the hatch can be opened from both sides;

.4 examination of lift trunks and lift cars to check the possibility of evacuation when the lift stops between exit levels in the event of power failure. Checking whether the lift car is fitted with an escape hatch and the lift trunk is provided with an emergency escape ladder

13.1.1.4 Fire Protection of Machinery Spaces – required scope of activities:

.1 examination of machinery spaces – checking if the spaces are clean and properly maintained (no evidence of contamination, leakages, etc. by flammable products which may be a cause of fire);

.2 operation test of the means of control for closing all openings leading to machinery spaces, such as: doors, manholes, ventilation heads and louvres;

.3 operation test of remote stopping inlet and exhaust ventilation fans;

.4 operation test of remote closing of: boiler supply fans, fuel transport pumps, lubricating oil and thermal oil circulating pumps, as well as oil separators;

.5 operation test of remote closing of quick-closing valves on oil fuel pipes of storage tanks, settling and daily service tanks, located in the machinery space above the double bottom;

.6 checking that insulating materials (of ship sides, divisions, ceilings, casings, ventilation ducts, piping, etc.) in machinery spaces are provided with a suitable coating to protect such materials against the penetration of oil vapours;

13.1.1.5 Fire protection of galley spaces and pantries:

.1 internal examination of under ceiling space in galleys (through inspection dampers) – checking if they are free of grease and contamination;

.2 operation test of stopping mechanical ventilation provided in a galley space.

13.1.1.6 Galley exhaust duct – required scope of activities:

.1 external examination of such system components as fire-extinguishing medium container, flexible hoses, control valves, fire dampers, pipes, discharge nozzles, etc.;

.2 internal examination of grease trap and exhaust ventilation duct (through inspection hatches) – checking that the duct walls are free of grease build-up;

.3 operation test of manual control of fire dampers in the lower and upper parts of duct.

13.1.1.7 Ventilation systems – fire dampers – required scope of activities:

.1 external examination and operation test of the means of closure of air intake and exhaust openings of all ventilation systems;

.2 operation test of the remote stopping of fans in ventilation systems;

.3 external examination of all accessible fire dampers in ventilation ducts;

.4 operation test of all ventilation controls interconnected with fire-protection systems.

13.1.2 5 year survey

13.1.2.1 Fire divisions – required scope of activities

.1 close-up examination of selected fire divisions – checking the condition and securing of insulation (if any), checking the insulation adhesion to bulkheads, ceilings and ventilation ducts, checking the condition of the division surface materials, checking the integrity of division plates (for laminations) if fabricated from ready-made plates:

- in accommodation spaces, service spaces and in control stations
- in machinery spaces;

.2 close-up examination of selected draught stops within accommodation area (if any) – checking the condition and securing of insulation, visual examination of the draught stop integrity.

13.1.2.2 Low-location lighting of escape routes – required scope of activities:

.1 testing the luminance of all low-location lighting – checking the lighting intensity, in accordance with the recommendations specified in IMO Res. A.752(18) and ISO 15370 Standard.

13.1.2.3 Ventilation systems – fire dampers – required scope of activities

.1 operation test of one of automatic fire dampers in fire divisions by simulation of exceeded temperature setting.
