

# RULES

## FOR THE CLASSIFICATION AND CONSTRUCTION OF SEA-GOING SHIPS

### PART XVI

#### STRUCTURE AND STRENGTH OF FIBER-REINFORCED PLASTIC SHIPS

ND No. 2-020101-152-E



**St. Petersburg**  
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# **RULES FOR THE CLASSIFICATION AND CONSTRUCTION OF SEA-GOING SHIPS**

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Rules for the Classification and Construction of Sea-Going Ships of Russian Maritime Register of Shipping have been approved in accordance with the established approval procedure and come into force on 1 January 2022 (except for Part XX which came into force on 15 March 2022).

The present edition of the Rules is based on the 2021 edition taking into account the amendments and additions developed immediately before publication.

The procedural requirements, unified requirements, unified interpretations and recommendations of the International Association of Classification Societies (IACS) and the relevant resolutions of the International Maritime Organization (IMO) have been taken into consideration.

The Rules are published in the following parts:

Part I "Classification";

Part II "Hull";

Part III "Equipment, Arrangements and Outfit";

Part IV "Stability";

Part V "Subdivision";

Part VI "Fire Protection";

Part VII "Machinery Installations";

Part VIII "Systems and Piping";

Part IX "Machinery";

Part X "Boilers, Heat Exchangers and Pressure Vessels";

Part XI "Electrical Equipment";

Part XII "Refrigerating Plants";

Part XIII "Materials";

Part XIV "Welding";

Part XV "Automation";

Part XVI "Structure and Strength of Fiber-Reinforced Plastic Ships";

Part XVII "Distinguishing Marks and Descriptive Notations in the Class Notation Specifying Structural and Operational Particulars of Ships";

Part XVIII "Additional Requirements for Structures of Container Ships and Ships, Dedicated Primarily to Carry their Load in Containers". The text of the Part is identical to IACS UR S11A "Longitudinal Strength Standard for Container Ships" (June 2015) and S34 "Functional Requirements on Load Cases for Strength Assessment of Container Ships by Finite Element Analysis" (May 2015);

Part XIX "Additional Requirements for Cargo Ships of Less Than 500 Gross Tonnage";

Part XX "Additional Requirements for Yachts";

Supplement to Rules and Guidelines of Russian Maritime Register of Shipping "IACS Procedural Requirements, Unified Requirements, Unified Interpretations and Recommendations".

**REVISION HISTORY<sup>1</sup>**

(purely editorial amendments are not included in the Revision History)

| Amended<br>paras/chapters/sections | Information on amendments                                                                                                                                                    | Number and date<br>of the Circular<br>Letter | Entry-into-force<br>date     |
|------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|------------------------------|
| <a href="#">Annotation</a>         | Annotation has been amended in connection with issuing new Part XX "Additional Requirements for Commercial Yachts". Annotation has been specified due to renaming of Part XX | —<br><br>312-09-1747c<br>of 14.04.2022       | 15.03.2022<br><br>14.04.2022 |
| <a href="#">Table 2.3.3.8</a>      | Values of shear modulus and ultimate shear strain for PVC foam with density of 200 have been specified                                                                       | 314-04-1778c<br>of 27.05.2022                | 01.07.2022                   |

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<sup>1</sup> Amendments and additions introduced at re-publication or by new versions based on circular letters or editorial amendments.

## **1 GENERAL**

### **1.1 APPLICATION**

**1.1.1** The requirements of this Part of the Rules are applicable to hulls and superstructures manufactured of fiber-reinforced plastic (FRP) for the following ships:

- .1** displacement ships of 15 — 70 m in length, inclusive;
- .2** high-speed displacement craft with a Froude number within the range of  $Fr_v \approx 1.0 - 2.5$ ;
- .3** boats and motorboats of 4,5 — 15 m in length with a Froude number  $Fr_v < 2,5$ .

**1.1.2** The requirements of this Part of the Rules are in addition to the requirements applicable to superstructures manufactured of FRPs for metal hull displacement ships.

**1.1.3** Hulls and superstructures manufactured of FRPs for ships and boats designed to the RS class but not specified in [1.1.1](#) shall be reviewed by the Register together with technical background such as normative documents, calculation and test results. Technical background shall confirm the safety level of a structure or a product to be not lower than the one required by the relevant RS rules. In such case, the provisions of this Section and [Section 2](#) shall be applied.

## **1.2 DEFINITIONS AND EXPLANATIONS**

**1.2.1** Definitions and explanations relating to the general terminology of the Rules are given in 1.1 of Part I "Classification".

The definitions of ship dimensions comply with the provisions of Part II "Hull".

**1.2.2** For the purpose of this Part the following definitions have been adopted:

FRP means material with heterogeneous nature and consisting of reinforcement elements and polymer matrix.

Particles and fibers are applied as reinforcement elements. Using FRP with reinforcement elements not mentioned in this Part of the Rules is allowed provided that the relevant technical justification including strength tests and calculations of hull structures made of FRP is provided.

Homogeneous FRP means material made up with layers of reinforcement elements of the same type and the same chemical nature, with the same reinforcement scheme.

Non-homogeneous FRP means material made up with layers of reinforcement elements of different types but the same chemical nature.

Hybrid FRP means material made up with layers based on reinforcement elements of different chemical nature, or with individual layers, each made of reinforcement elements of the same chemical nature.

Fiber means glass, carbon or aramid type reinforcement element used in the form of the following:

rovings (woven rovings);

tapes;

woven fabrics;

multiaxial (non-crimp) fabrics.

Roving (woven roving) means numerous fibers connected to each other.

Tape means numerous rovings transversally interconnected to each other.

Mat means FRP consisting of chops 3 – 20 mm long randomly arranged on the plane, on the basis of the polymer matrix, where microspheres may be added.

Multiaxial (non-crimp) fabric means material made up with layers of tapes with one-directional reinforcement, superimposed on each other at specified angles, and interconnected with each other.

Depending on the number of reinforcement directions, multiaxial (non-crimp) fabrics are classified into the following types:

biaxial fabrics with two reinforcement directions, generally 0° and 90° or + 45° and –45°;

triaxial fabrics with three reinforcement directions, mainly 0°, + 45° and –45°;

quadriaxial fabrics with four reinforcement directions, usually 0°, + 45°, –45° and 90°.

Woven fabric means material made by weaving twisted fibers or rovings according to a weaving technique used in the textile industry with different weave types (satin, plain, twill, etc.).

Prepreg means reinforcement elements such as tapes, woven fabrics or multiaxial (non-crimp) fabrics pre-soaked in thermosetting binder, which cures under certain conditions (temperature and/or pressure).

Particle means reinforcement element as a glass or polyester microsphere used in shipbuilding structures, in such materials as spheroplastic and mat.

Polymer matrix means a binder in cured state, on the basis of thermoset organic resin (polyester, vinylester, epoxy, etc.) with a curing system and various additives (a catalyst, an accelerant, thixotropic agent and colour pigment).

Spheroplastic means FRP consisting of microspheres and polymer matrix.

Adhesive means glue/filler, which is an organic matter intended for jointing structural members manufactured of FRP and filling clearances between them, compatible with a polymer matrix.

Foam plastic means material with the lower density than that of water, having a porous structure, mainly close-cellular one, compatible with a polymer matrix of load-bearing layers.

Sandwich construction means a structure consisting of outer load-bearing layers manufactured of FRP and a core, where foam plastics, spheroplastics, mats, and such structural members as honeycombs, ribs, corrugations of various configurations may be applied. The latter may be used separately or in combination with foam plastics and spheroplastics filling the free space between these members.

Contact moulding technique means a method including laying the reinforcement material (fabric, mat) soaked on binder into a matrix or on a punch, followed by its compaction and removal of air bubbles.

Spraying technique means a version of the contact moulding technique when moulding is performed by laying-up of chopped fibers with binder on the matrix or punch surface, followed by ply-down and compaction of material.

Closed moulding techniques means a common name for the techniques of impregnation of the dry reinforcement material in a closed plane with a liquid binder moving through this material.

Infusion technique means one of the closed moulding techniques, when the reinforcement material is soaked in binder due to the vacuum created in a pressure-tight plane formed with a matrix where the dry reinforcement material is laid and with a leak-tight film adjacent tightly to the matrix.

RTM (Resin Transfer Moulding) technique means closed moulding techniques differing from the infusion technique by the fact that a pressure-tight plane is formed between a rigid matrix where the dry reinforcement material is laid and with a rigid punch adjacent tightly to it. The binder is forced to move over the reinforcement material by the pressure created therein, or due to simultaneous vacuum and pressure in the binder.

### 1.3 GENERAL

**1.3.1** When designing FRP structures physical and mechanical properties of the material shall be taken into account, including the main ones:

- elastic and strength anisotropy of material properties;
- its dependence on properties of basic components (reinforcement elements, cores and binders), their quantitative ratio, as well as on laying directions of these elements (reinforcement scheme);
- comparatively low interlaminar shear strength and transverse tension;
- lower Young's moduli than those of typical shipbuilding materials such as steel, titanium and aluminum alloys;
- nearly absence of plastic deformations.

**1.3.2** Design of a ship hull manufactured of the FRPs and its basic members shall be accompanied by development of their manufacturing techniques, requirements for quality control and performance standards, with due regard of the shipyard production facilities, availability of proved moulding and assembly processes, and quality control procedures.

**1.3.3** Closed moulding techniques are preferred in development of structures manufacturing procedures, such as infusion and RTM techniques ([refer to 1.2.2](#)).

Application of the contact moulding technique shall be limited and is allowed in structures where it is technically feasible and when other moulding techniques cannot be applied.

In all cases, the procedure of FRP structures manufacture shall be agreed with the Register.

**1.3.4** When selecting the hull framing system, it is recommended to minimize the number of frames that support the hull shell (deck plating, bulkhead plating) and reduce the number of joint intersections of frames in different directions, thus contributing to the structural strength.

**1.3.5** Primary members (stringers, deck girders or web frames (frames changing to floors and beams)) shall be made continuous. To comply with this requirement, members of inter-perpendicular directions shall have different depths at intersections.

Application of intercostal framing members is allowed provided their ends are durably fastened.

**1.3.6** Composition and structure of the hull shell plating and upper deck plating shall be selected subject to condition of maximum bending stiffness in main directions, with required strength characteristics ensured.

To satisfy this requirement, the hybrid reinforcement using reinforcement materials different in type, stiffness and density, and cores, shall be applied.

**1.3.7** Hull shell plating and plating of decks shall be made with variable thickness of members in accordance with their stress-strain behavior.

Thickness variation shall be smooth due to adding (removing) partial layers of the reinforcement material between its continuous layers.

**1.3.8** Local reinforcement of members is allowed to be manufactured by additional moulding to increase the basic thickness only when vacuum injection techniques are applied for their manufacture.

Additional moulding on the basic thickness by the contact moulding technique is only allowed where outfittings, individual elements of the equipment and systems are fastened, and in special cases stated in the relevant sections of this Part of the Rules.

**1.3.9** All local thicknesses and connecting elements (moulding-on straps, sheathings, moulding-in angles, etc.) shall have variable thickness with smooth reduction towards edges. In such case, each layer of fabric shall overlap the preceding one in accordance with the requirements specified in [3.2.1](#) and [3.2.2](#).

**1.3.10** Any design and technology solutions other than those stated in this Part of the Rules shall be agreed with the Register.

## **1.4 TECHNICAL DOCUMENTATION**

**1.4.1** Prior to manufacture of the ship's hull and superstructures, including the following:  
decks, platforms and their individual sections;  
bulkheads;  
tanks;  
seatings for main engines and other machinery and arrangements subject to survey by the Register, technical documentation of the hull in the scope specified in 3.2.3 of Part I "Classification" shall be submitted to the Register for review and approval.

**1.4.2** The technical documentation of the hull shall be supplemented by technical specifications on FRPs and reference guidelines on the manufacturing procedure (technological instruction). The abovementioned documents shall contain the following:

- complete list of basic components (reinforcement materials, resins, curing agents, glues, etc.) used in manufacture of FRP structural members, as well as production and auxiliary materials;

- composition of FRPs, physical and mechanical characteristics, chemical formulation of a binder;

- information on the RS approval (Certificates) for basic materials, cores (if any);

- requirements for the equipment to be used in moulding hull structures and construction documentation on its manufacture;

- list of measures to be taken for manufacture preparation of hull structures, including the list of the process equipment required for production;

- technological instructions for moulding of hull structures, their individual members and elements, as well as assembly instructions;

- requirements for structures cure conditions;

- requirements for quality control, including allowances for maximum permissible defects;

- technological instructions for repair of impermissible defects.

**1.4.3** The construction documentation for FRP structures, in addition to conventional designations of scantlings and thicknesses, shall specify the material brand and composition (reinforcement material and binder brands), reinforcement scheme layer by layer, density of laying up (surface density), number of reinforcement material layers.

## **1.5 SCOPE OF SURVEYS**

**1.5.1** After review and approval of the technical design of a ship, including the list of technical documentation specified [1.4](#), the following items shall be subject to the RS survey for compliance with the requirements of [1.4.2](#):

- basic components of FRPs (reinforcement materials, resins, curing agents, cores, etc.), which shall be approved by the Register ([refer to Section 2](#)), have technical specifications and be supplied together with Manufacturer's Certificate of Quality per batch, to confirm compliance of their characteristics to those stated;

- storage conditions and incoming inspection results of FRP basic components;

- condition of production spaces and equipment for moulding of hull structures in accordance with the requirements of the technique selected;

- microclimate in production spaces and means to maintain the spaces within specified limits as required by technological instructions;

- equipment to be used in moulding hull structures, production facilities and measurement means;

- moulding of hull structures, their members and elements, as well as assembly processes in accordance with technological instructions;

- heat treatment conditions of hull structures, their members and elements;

- quality performance control of completed hull structures, their members and elements.

**1.5.2** Tests of completed structures and their individual members shall be carried out when new engineering solutions and/or manufacturing procedures that are not regulated by these Rules are applied in construction of hulls and superstructures using FRPs. Test schedules and procedures shall be developed by the firm (manufacturer) and approved by the Register.

**1.5.3** Tests of specimens cut out from allowances and cutouts shall be carried out during quality performance control of hull structures and their individual members for the hull of a prototype ship of a series, and in case of any changes in the composition of FRP. Test schedules and procedures shall be developed by the firm (manufacturer) and approved by the Register.

## **2 MATERIALS**

### **2.1 GENERAL**

**2.1.1** These requirements apply to structural FRP based on reinforcement cores manufactured of glass and/or carbon fibers, as well as aramid fibers, thermosetting polymer binders: polyester, vinylester and epoxy ones, which are applied for manufacture of hulls and superstructures of various displacement, including motorboats and boats.

**2.1.2** General requirements:

manufacture procedure of structures shall ensure sustained quality and possibility of application of high-efficiency moulding techniques and mechanical aids;

hull structures shall maintain their qualities primarily operability and reliability, during operation under sea conditions within specified temperature ranges (from -40 °C to +60 °C) for a long period of time, at least 20 years;

materials, procedures and construction solutions applied shall ensure maintainability of structures both at the manufacturer and when at sea.

**2.1.3** Structural FRPs and cores approved by the Register delivered in accordance with standards and provided with technical specifications for industrial supply, as well as Manufacturer's Certificates per batch ([refer to 2.2](#)) shall be used for ship structures.

**2.1.4** FRP applied in ship structures shall comply with the requirements of this Part containing complete list of type tests and checks every material shall be subject to.

**2.1.5** Tests to be carried out for new FRP not specified in this Part of the Rules are listed in type test program specified in [Appendix 2](#).

## **2.2 SCOPE OF TECHNICAL SUPERVISION**

**2.2.1** FRP intended for manufacture of hulls or ship structures, as well as binders for manufacture of FRPs and cores shall be approved by the Register (provided with Type Approval Certificate (CTO) and/or Register Certificate per batch) in accordance with Part I "General Regulations for Technical Supervision" of the Rules for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships. The Register Certificate for FRP is not required provided the requirements specified in [2.2.4.3](#) of this Part of the Rules are met. Application of FRP binders for boats is allowed based on the report documents of firms (manufacturers) or laboratories recognized by the Register.

Register approval for reinforcement materials applied for FRP manufacture is recommended ([refer to 2.3.1.6](#)).

**2.2.2** Register Certificates are issued to a material firm (manufacturer) based on the approved documentation, results of materials tests for verification of compliance with the requirements of these Rules ([refer to 2.3.1 — 2.3.3, 2.3.5](#)), direct survey of production (for drawing up of the Type Approval Certificate (CTO)) and check tests of serial products. Tests shall be performed by a firm's (manufacturer's) laboratory or another laboratory recognized by the Register.

Where the production is transferred to another firm (manufacturer), the Type Approval Certificate (CTO) shall be issued based on the results of technical supervision and check tests.

The check test program shall be developed by the firm (manufacturer) taking into account the standards of quality performance control and approved by the Register.

### **2.2.3 Technical supervision for manufacture at the firm (manufacturer) for drawing up of the Type Approval Certificate (CTO).**

**2.2.3.1** The technical supervision includes the following:

- review and analysis of documents submitted by the firm (manufacturer) ([refer to 2.2.3.2](#)) confirming the capability of firm (manufacturer) to manufacture products of sustained quality in required amounts;

- survey of the firm (manufacturer), including assessment of the product manufacture quality system and carrying out of check tests required ([refer to 2.2.3.3](#));

- drawing up of the Type Approval Certificate (CTO) for products manufactured ([refer to 2.2.3.4](#)).

**2.2.3.2** The firm (manufacturer) shall submit the following information to the Register for review:

- outline of firm (manufacturer), containing the information on its organization structure, production and management structure, affiliation or form of ownership;

- list of materials produced, their characteristics, delivery specifications with the letter not lower than "O1", and other technical documentation confirming the stated characteristics of materials;

- technological instructions on materials/structures manufacture using FRPs (as applicable) and the quality performance control standards;

- instructions on stacking and storage of basic components for manufacture of materials, and their incoming inspection;

- report containing the information on the equipment and quality control instruments used during manufacture of materials, and qualification level of laboratory personnel involved in quality performance control product;

- Manufacturer's Certificates of Quality confirming availability of an implemented Quality Management System at the firm (manufacturer);

- check test program for product specimens;

- results of material tests for compliance with the requirements of these Rules, and check tests of material specimens to confirm characteristics stated and ability of using materials as intended.

**2.2.3.3** Upon satisfactory results of the technical documentation review specified in [2.2.3.2](#), the firm (manufacturer) shall be subject to survey to verify the organization condition and product quality control system management, and availability of conditions for manufacture of required volume of products in accordance with the requirements of Section 8, Part I "General Regulations for Technical Supervision" of the Rules for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships.

**2.2.3.4** Upon satisfactory survey results of the firm (manufacturer) considering the requirements of Section 6, Part I "General Regulations for Technical Supervision" of the Rules for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships, the Register shall draw up the Type Approval Certificate (CTO) for materials produced.

**2.2.3.5** The Type Approval Certificate (CTO) shall be provided with indication of the fire hazardous properties of the material with the reference to the International Code for Application of Fire Test Procedures, 2010, adopted by IMO resolution MSC.307(88), as amended by IMO resolution MSC.437(99) (FTP Code), and appropriate protocols based on tests of FRPs carried out in laboratories recognized by the Register. In the absence of such tests, the Type Approval Certificate (CTO) shall contain the following text: "fire hazardous properties of the material were not determined".

In addition, the following text shall be entered in the Type Approval Certificate (CTO): "In the case of using the material as part of fire-proof divisions, these divisions shall be tested in compliance with the International Code for Application of Fire Test Procedures, 2010, adopted by IMO resolution MSC.307(88), as amended by IMO resolution MSC.437(99) (FTP Code)".

**2.2.4 Technical supervision during manufacture of hull/structures using FRP.**

**2.2.4.1** Prior to manufacture, the manufacturer (a shipyard) shall submit the following:  
approved technical documentation in the scope specified in [1.4.2](#) (technical specifications on FRPs, technological instruction);

reports on fire test results of FRPs carried out in laboratories recognized by the Register, with a conclusion on compliance of the fire-proof division with the requirements of these Rules according to which the ship design is approved, if applicable;

protocols on tests of the fire-proof divisions carried out in laboratories recognized by the Register in accordance with the requirements of the International Code for Application of Fire Test Procedures, 2010, adopted by IMO resolution MSC.307(88) (FTP Code);

where FRPs other than those stated in this Part of the Rules are used, protocols on FRP tests carried out in accordance with the test program approved by the Register ([refer to Appendix 2](#)).

**2.2.4.2** Technical supervision shall include the following:

review of documents submitted by the firm (manufacturer) in a scope specified in [2.2.3.2](#) to confirm its capability of manufacturing FRP products of stable quality in required volumes;

survey of the firm (manufacturer) to assess its capability of manufacturing FRP hulls/structures and quality control systems;

technical supervision during manufacture in a scope specified in [1.5.1](#);

technical supervision during tests of FRP specimens cut out from manufacturing allowances or witness sample (as applicable), complying with the technical documentation on the product manufactured;

technical supervision of hull defects detection and repair.

Upon results of technical supervision during construction of hull or structure using FRPs, the report documents of shipyard shall be signed by the Register surveyor in accordance with the provisions of Section 13 "Technical Supervision at the Shipyard during Construction of Ships", Part I of the Rules for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships, attaching Register Certificates for materials.

**2.2.4.3** Where the Register Certificate for FRP is not available during technical supervision in the course of construction of hull or structure using FRPs, in addition to the

requirements specified in Section 13 "Technical Supervision at the Shipyard during Construction of Ships", Part I of the Rules for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships the Report on Survey (form 6.3.29) shall be drawn up to confirm that the requirements for FRP specified in this Part of the Rules are met.

**2.2.5** In case of serial production of FRP hulls/structures (two and more), the Report on Survey ([refer to 2.2.4](#)) may be substituted with the Type Approval Certificate (CTO) for FRP hull/structures taking into account the compliance with the requirements of Sections 6 and 8, Part I "General Regulations for Technical Supervision" of the Rules for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships. In such case, the manufacturer's report on FRP hull/structures (passport, Manufacturer's Certificate of Quality, etc.) shall be submitted.

## 2.3 REQUIREMENTS FOR FRP CHARACTERISTICS AND THEIR BASIC COMPONENTS

### 2.3.1 Reinforcement materials.

**2.3.1.1** Reinforcement materials in FRPs shall ensure specified stiffness and strength characteristics, including the material exposed to various operational factors (external forces, temperature, humidity, etc.).

**2.3.1.2** To ensure the adhesion strength between fibers and polymer matrix, a hydrophobic-adhesive (coupling agent) shall be applied on the fiber surface, the adhesive being compatible with the binder type – polyester, vinylester or epoxy one.

A procedure of applying a hydrophobic-adhesive (coupling agent) shall ensure coating resistance to mechanical impacts.

**2.3.1.3** Glass reinforcement materials (fabrics, tapes, mats) for constructional fiber glass plastics shall be manufactured from fibers of standard non-alkaline aluminoborosilicate glass, grade E, or high-modulus magnesium aluminosilicate glass, grade S. Characteristics of the specified glass fibers used in reinforcement materials shall be not lower than the values provided in [Table 2.3.1.3](#).

Table 2.3.1.3

Physical and mechanical characteristics of basic fiber types used in ship structures

| Characteristic                        | Glass fibers   |                | Carbon fibers | Aramid fibers |
|---------------------------------------|----------------|----------------|---------------|---------------|
|                                       | Glass, grade E | Glass, grade S |               |               |
| Density, in kg/m <sup>3</sup>         | 2500 – 2550    | 2550 – 2580    | 1800          | 1420          |
| Young's modulus of elongation, in GPa | at least 70    | at least 90    | at least 250  | at least 120  |
| Ultimate tensile strength, in GPa     | at least 3,0   | at least 4,0   | at least 4,5  | at least 3,0  |
| Ultimate tensile elongation, in %     | 4,5            | 4,5            | at least 1,6  | 2,5 – 3,5     |

**2.3.1.4** Carbon reinforcement materials (fabrics, tapes) for constructional carbon fiber-reinforced plastics shall be manufactured from high-strength 3K, 6K, 12K<sup>1</sup> fibers with characteristics in accordance with [Table 2.3.1.3](#).

Application of high-modulus fibers with a Young's modulus of more than 350 GPa and ultimate elongation less than 1,1 % is allowed in members subjected mainly to compression loads.

**2.3.1.5** Characteristics of aramid fibers as part of tapes and fibers ([refer to Table 2.3.1.3](#)) shall ensure efficient application thereof as part of ship structures exposed mainly to significant impact and vibration loads.

Considering their increased water absorption, reinforcement materials manufactured of these fibers are recommended for application inside a laminated package between monolayers based on glass and/or carbon materials to prevent aramid fibers from water contact.

**2.3.1.6** Fibers and reinforcement materials on their basis shall be tested for compliance of their mechanical properties with stated ones. The testing shall be carried out according to the methods of international and/or national standards, or other documents agreed with the Register.

The list of parameters to be tested is determined by technological instructions and quality control standards. If Type Approval Certificate (CTO) is available, the testing shall be carried out by the firm (manufacturer) of fibers and reinforcement materials, and the results shall be recorded in the Manufacturer's Certificate of Quality of each product batch produced ([refer to 2.2.1](#)). The testing may be also carried out by the shipyard or firm (manufacturer) of FRP products and structures, or other laboratories recognized by the Register. Test reports shall be submitted to the Register.

<sup>1</sup> 1K = 1000 fibers.

**2.3.1.7** Reinforcement materials applied in FRPs shall have certain wettability and drapability properties to be combined with a selected type of thermoset binder when moulding irregular-shaped structures.

When closed moulding techniques are applied for reinforcement materials, permeability factor shall be estimated to determine process parameters in selection of a binder injection strategy.

**2.3.1.8** Manufacturer's Certificate of Quality drawn up for each fiber (reinforcement material) batch shall contain the following information:

- firm's (manufacturer's) data;
- fiber (material) brand mark;
- reinforcement type and scheme (for reinforcement material);
- weight per unit length or area;
- acceptance test results ([refer to 2.3.1.6](#)).

**2.3.1.9** The firm (manufacturer) of reinforcement materials or FRP structures ([refer to 2.2.1](#)) shall verify laminating properties of these materials by manufacturing laminates of them, using contact moulding and infusion techniques based on selected polyester and vinylester binders.

Specimens shall be cut out from these laminates in main directions of reinforcement and tested according to the methods of international and/or national standards, or other methods agreed with the Register, to determine the following:

- ultimate strength and Young's modulus of elongation;
- ultimate bending strength;
- ultimate interlaminar shear strength.

Standards and methods to be used in determining of the specified characteristics are listed in the type test program ([refer to Appendix 2](#)).

**2.3.1.10** When used in structures, reinforcement materials may be applied in the form of woven fabric, multiaxial (non-crimp) fabrics, tapes and mats.

Selection of the reinforcement material type, combination thereof and reinforcement scheme depends on the requirements for the FRP, conditions of its operation as part of a structure and its function. In this case, scantlings of the structure and its primary members, their shape and manufacture procedure shall be taken into account ([refer to 2.3.5](#)).

## **2.3.2 Binders.**

**2.3.2.1** The following parameters shall be determined for thermosetting binders used in FRP ([refer to 2.1.1](#)):

- mechanical properties that ensure proper strength and rigidity characteristics in FRPs;
- adhesion to fibers of reinforcement materials under all exposures of FRPs during operation;
- water absorption and resistance when subjected to long-term exposure to sea water;
- heat resistance within the temperature range of  $-40\text{ }^{\circ}\text{C}$  to  $+60\text{ }^{\circ}\text{C}$ ;
- resistance to oil and petroleum products.

**2.3.2.2** Physical and mechanical properties of polyester and vinylester binders as cured shall comply with the requirements specified in [Table 2.3.2.2](#).

Table 2.3.2.2

**Physical and mechanical characteristics of main binder types used in ship structures**

| Characteristic                                          | Polyester binder  | Vinylester binder | Epoxy binder       |
|---------------------------------------------------------|-------------------|-------------------|--------------------|
| Density, in $\text{kg/m}^3$                             | 1100 – 1300       | 1130 – 1180       | 1150 – 1280        |
| Tensile strength, in MPa                                | at least 65       | at least 75       | at least 100       |
| Young's modulus of elongation, in GPa                   | at least 3,0      | at least 3,3      | at least 3,5       |
| Bending strength, in MPa                                | at least 90       | at least 135      | at least 150       |
| Tensile elongation, in %                                | 2 – 3             | 4 – 5             | 3 – 6              |
| Water absorption at a normal pressure within 24 h, in % | not more than 0,1 | not more than 0,1 | not more than 0,08 |

**2.3.2.3** Epoxy binders used in moulding individual structural elements and members, and as prepreg components, shall have characteristics not lower than those specified in [Table 2.3.2.2](#), as cured. In such case, curing shall be carried out at shipbuilding facility.

Taking into account that epoxy binders are mostly related to hot-curing resins, their application in manufacture for ship structures shall be justified by production processes.

**2.3.2.4** Binders shall be adaptable and have viscosity and wettability that ensure proper impregnation of reinforcement materials, and allow closed moulding techniques for structures manufacture and mechanization of their manufacture process.

Binder pot life shall ensure manufacture of large-sized irregular-shaped structures with relatively thick members.

**2.3.2.5** All components (catalysts, accelerants, thixotropic agents, colour pigments) constituting the thermosetting binder shall be compatible with resin, ensure complete curing of the binder without deterioration of its properties when cured.

**2.3.2.6** Colour pigments shall be resistant to climatic factors. Pigment amount added to the binder shall not exceed the standard established by the resin manufacturer.

**2.3.2.7** Binders applied in closed moulding techniques shall have the following characteristics:

- dynamic Brookfield viscosity at a temperature of 25 °C – 150 – 400 mPa·s;
- gel time at a temperature of 18 – 22 °C, variable within the range of 0,5 – 6 h, with physical and mechanical properties remaining unchanged;
- temperature of exothermic reaction with binder polymerization – not more than 200 °C;
- heat treatment temperature – not more than 80 °C;
- glass transition temperature of binder as cured – not less than 110 °C.

**2.3.2.8** Firms (manufacturers) of thermosetting binders shall confirm their characteristics by estimation of properties in the course of and after curing. The list of properties to be estimated shall be determined by the documentation on production process and quality performance control requirement and agreed with the Register.

Tests to determine binder characteristics shall be carried out by the firm (manufacturer) according to the international and/or national standards, or other documents agreed with the Register.

Testing may be also carried out by a laboratory recognized by the Register.

**2.3.2.9** Each binder batch shall be provided with a Manufacturer's Certificate of Quality containing the following information:

- firm's (manufacturer's) data;
- binder type;
- binder brand mark;
- acceptance test results.

Instructions on binder use and storage conditions shall be enclosed with the Manufacturer's Certificate of Quality.

### **2.3.3 Cores.**

**2.3.3.1** Materials used as cores in sandwich (multi-layered) constructions of a ship, and in cores of closed box stiffeners shall have relevant strength and stiffness at minimum density to ensure combined operation of load-bearing layers in these structures and stiffener sheathings under all impacts during operation.

**2.3.3.2** Core materials shall be compatible with materials of load-bearing layers and sheathings. The binder of load-bearing layers shall not change the structure and impair characteristics of the core material whereas the latter shall not change curing properties of the binder.

Where adhesive is used for jointing FRP and core layers, it shall ensure their formation in a single structure under all operational impacts, and be compatible with the binder and core.

**2.3.3.3** When selecting core materials used in external structural members (hull shell, superstructure sides, etc.), it is recommended to use cores with low water absorption,

resistance to ageing due to temperature differential and exposure to ultraviolet irradiation, and, when possible, proper thermal insulation.

**2.3.3.4** The following materials may be used as a core of external members in sandwich (multi-layered) constructions:

- polyvinyl chloride (PVC) foams of the rigid close-cell type;
- polyurethane (PUR) foam;
- balsa wood;
- lightweight mats with microspheres ([refer to 1.2](#)).

To increase rigidity and strength of PVC foams, PUR foams and lightweight mats, especially to lateral shear strength, additional reinforcement may be introduced, such as layers of reinforcement material, corrugations, ribs, etc. Use of additional reinforcement shall be substantiated.

**2.3.3.5** Constructional discrete types of cores such as honeycombs, corrugations, ribs (without using of expanded-type core, e.g. foam plastic) may be used in inner members of hulls and superstructures, except those specified in [2.3.3.4](#).

**2.3.3.6** Polyvinyl chloride (PVC) foams shall be used in closed box stiffeners of framing.

**2.3.3.7** Use of other core types in sandwich (multi-layered) constructions and closed box stiffeners shall be substantiated based on calculation and test results and agreed with the Register.

**2.3.3.8** Physical and mechanical properties of PVC foams and PUR foam specified for the relevant typical density values shall comply with the requirements in [Table 2.3.3.8](#). Their properties related to intermediate density values shall be determined by extrapolation.

Table 2.3.3.8

**Physical and mechanical properties of PVC foams and PUR foam**

| Characteristic                                     | Foam plastic  |              |              |               |              |              |
|----------------------------------------------------|---------------|--------------|--------------|---------------|--------------|--------------|
|                                                    | PVC foam      |              |              | PUR foam      |              |              |
| Density, in kg/m <sup>3</sup>                      | 40            | 100          | 200          | 35 — 55       | 100 — 120    | 200 — 220    |
| Compression strength (at 10 % deformation), in MPa | at least 0,4  | at least 1,5 | at least 4,0 | at least 0,2  | at least 0,9 | at least 2,5 |
| Young's compression modulus, in MPa                | 30            | 100          | 250          | 7,5 — 10      | 25 — 35      | 100 — 120    |
| Tensile strength, in MPa                           | at least 0,7  | at least 2,5 | at least 6,0 | at least 0,16 | at least 0,8 | at least 2,0 |
| Young's elongation modulus, in MPa                 | 25            | 80           | 180          | —             | —            | —            |
| Shear strength, in MPa                             | at least 0,40 | at least 1,5 | at least 3,5 | at least 0,1  | at least 0,5 | at least 1,0 |
| Shear modulus in laminate plane, in MPa            | 10            | 35           | 75           | —             | —            | —            |
| Ultimate shear strain, in %                        | 8             | 25           | 30           | —             | —            | —            |

**2.3.3.9** Firms (manufacturers) of PVC foams, PUR foam, honeycombs and other core types shall confirm their characteristics by carrying out testing of material specimens.

Procedure of specimen selection, a list of properties to be determined, and test procedures shall be established by firms (manufacturers) in the production documentation and quality performance control requirements, and agreed with the Register.

**2.3.3.10** Prior to moulding of sandwich (multi-layered) constructions and closed box stiffeners of framing with application of foam plastic as a core, the latter shall be machined to remove surface layers (slags) formed during manufacture.

Where closed moulding techniques are applied, the foam plastic shall be prepared by making channels for the binder to flow.

**2.3.3.11** Thermal treatment of structures with a core of foam plastic type shall be carried out at a temperature that does not cause any irreversible changes in the foam plastic resulting

in deterioration of its strength and elasticity properties and in its shrinkage and shape deformation.

**2.3.4 Adhesives.**

**2.3.4.1** Adhesives such as glues and fillers shall be used for jointing structural elements manufactured of FRPs. The latter may be filled with microspheres or chops and used for filling production spaces when jointing structural elements.

Glues and fillers shall be compatible with materials of elements jointed, ensure high strength of joint with due regard of the specified operating temperature range, resist to ageing, moisture and oil and petroleum products.

**2.3.4.2** Where possible, adhesives shall two-component, cured under standard conditions within approximately 20 – 60 min to allow elements of large-sized hull structures to be jointed under production conditions of shipyard.

**2.3.4.3** Adhesive shall provide the data on static shear strength and strength of the adhesive bondage when in initial state and after being moistened at the standard and increased temperature, as well as on determining fatigue and long-term stress-rupture strengths for these deformation types, for each pair of materials being jointed.

**2.3.4.4** When adhesives are used for jointing structural elements, preparation of their surfaces and procedure of adhesive application shall correspond to the recommendations of the firm (manufacturer). The adhesive thickness between structural elements being jointed shall not exceed the value specified by the manufacturer; air ingress therein is not allowed.

**2.3.4.5** When a structure containing adhesives is subjected to heat treatment under increased temperature, its value shall not exceed the curing temperature specified for the adhesive.

**2.3.4.6** Adhesive shall be delivered with a Manufacturer's Certificate of Quality containing the following information:

firm's (manufacturer's) data;

adhesive brand mark;

acceptance parameters and their numerical values, which shall be specified in the production documentation of the firm (manufacturer);

strength test results for selected pairs of materials being jointed.

**2.3.5 FRPs.**

**2.3.5.1** FRPs used in hull structures shall comply with the following basic requirements:  
have elasticity and strength characteristics required for making an effective hull structure, and operability under repeated static, permanent, vibration and impact loads;  
maintain their elasticity and strength characteristics, as well as operability within specified limits in the course of long-term operation in water and in different climate conditions for at least 20 years;

have low water absorption and high water resistance in sea water;

be resistant to oil and petroleum products as well as marine organisms.

The requirements for fire hazardous properties shall be determined depending on the ship type and provisions of the RS rules according to which the ship design was approved.

**2.3.5.2** The techniques of FRP processing to hull structures, their members and elements shall ensure the following:

manufacturing of the material as part of a structure with properties required;

reproduction of these properties when duplicating structures;

high manufacture quality without impermissible defects (delamination, pits, loose laying-up, etc.);

possibility of closed moulding techniques application (infusion, RTM techniques, etc.) and mechanization aids.

**2.3.5.3** The following techniques are allowed for manufacture of FRP structures:

contact moulding;

closed (vacuum) moulding, including infusion and RTM techniques;

spraying;  
moulding with the use of prepregs.

**2.3.5.4** When selecting technique for manufacture of structures, the maturity of this technique at the firm (manufacturer), availability of qualified personnel and required equipment shall be considered.

**2.3.5.5** To manufacture ship hull structures and their members, it is recommended to use mostly infusion technique.

To manufacture individual structural elements, RTM techniques are allowed.

**2.3.5.6** The contact moulding technique shall be applied in the areas of a structure where the infusion technique is impossible or inappropriate, e.g. in intersections or in strengthening areas.

**2.3.5.7** The spraying technique is allowed for manufacture of hull structures and their individual members to which the strength and rigidity requirements are not applied (not considered in strength calculations).

The spraying process shall be performed in accordance with the technological instruction, with the chops length within the range of 10 – 30 mm. It is recommended to apply spraying technique in layers. Rolling procedure to remove air and compact the material shall be carried out after each layer spraying.

**2.3.5.8** Moulding with the use of prepregs is allowed for ship hulls of up to 15 m in length, and for structural elements and members agreed with the Register. Prepreg properties shall comply with the requirements for their components – reinforcement material and binder.

**2.3.5.9** Moulding techniques shall ensure optimal ratio between the reinforcement material and binder to achieve the most balanced properties of the material.

Percentage content of reinforcement materials with glass and carbon fibers as reinforcement by mass depending on their type and moulding technique are specified in [Table 2.3.5.9](#).

Table 2.3.5.9

**Percentage content of reinforcement materials with glass and carbon fibers  
as reinforcement by mass in FRPs**

| Moulding technique       | Type of reinforcement material |              |               |               |
|--------------------------|--------------------------------|--------------|---------------|---------------|
|                          | Glass mats                     | Fiber glass  | Carbon fibers | Glass roving  |
| Contact moulding         | at least 0,3                   | at least 0,5 | at least 0,35 | –             |
| Closed (vacuum) moulding | –                              | 0,65 – 0,7   | 0,4 – 0,6     | –             |
| Spraying technique       | –                              | –            | –             | at least 0,35 |
| Using prepregs           | –                              | at least 0,7 | at least 0,45 | –             |

**2.3.5.10** Curing mode at higher temperatures shall not cause considerable residual deformations and impair the structural integrity. In case of sandwich (multi-layered) construction, a core of foam plastic type shall not experience irreversible changes that deteriorate its strength and elasticity properties ([refer to 2.3.3.11](#)).

**2.3.5.11** Basic characteristics of FRPs based on one-directional tapes (0°) and balanced scheme reinforced (0/90°) and (+45°/-45°) with glass fiber, carbon fiber, and polyester (vinylester) binder shall be not lower than those specified in [Table 2.3.5.11](#).

**2.3.5.12** Deterioration of elasticity and strength properties of FRPs after long-term exposure to operational factors for 20 years shall be equal to:

- for Young's modulus and shear modulus in laminate plane – less than 10 %;
- for strength properties – less than 20 %.

Table 2.3.5.11

**Basic characteristics of glass, carbon fiber-reinforced plastics**

| FRP type                                               | Reinforcement fiber |      |        |     |             |     |        |     |
|--------------------------------------------------------|---------------------|------|--------|-----|-------------|-----|--------|-----|
|                                                        | Carbon fiber        |      |        |     | Glass fiber |     |        |     |
|                                                        | Tape                |      | Fabric |     | Tape        |     | Fabric |     |
| Percentage content of reinforcement material by mass   | 0,4                 | 0,6  | 0,35   | 0,6 | 0,5         | 0,7 | 0,5    | 0,7 |
| Values of physical and mechanical properties, at least |                     |      |        |     |             |     |        |     |
| Young's modulus, in GPa                                | 65                  | 95   | 35     | 55  | 30          | 45  | 16     | 24  |
| Shear modulus in the reinforcement plane, in GPa       | 2,0                 | 3,5  | 5,5    | 6,5 | 2,0         | 2,5 | 3,0    | 4,5 |
| Tensile strength, in MPa                               | 850                 | 1200 | 500    | 800 | 550         | 700 | 250    | 400 |
| Compression strength, in MPa                           | 400                 | 500  | 350    | 400 | 300         | 400 | 200    | 300 |

**2.3.5.13** Water absorption by the FRP when exposed to sea water for a long period at normal pressure shall have the following values:

not more than 0,15 % of the material weight for 24 h of exposure to sea water;

not more than 3,0 % of the material weight after being exposed to sea water for 30 days.

**2.3.5.14** Strength and elasticity properties of FRP when exposed to various force impacts (short-term, repeated static, long-term, etc.), and after being moistened and impacted with increased temperatures, shall be determined by test procedures specified in type test program ([refer to Appendix 2](#)).

**2.3.5.15** Manufacture of FRP structures shall be performed simultaneously with quality performance control at all production stages in accordance with the applicable reference documents.

The quality performance control methods applied shall detect impermissible deviations from the production process, including various defect types that may deteriorate strength and operability of a structure.

**2.3.5.16** The Register may carry out quality performance control of random FRP structures and products, upon which a decision on material approval shall be made.

### 3 HULL AND SUPERSTRUCTURES OF SHIPS

#### 3.1 HULL STRUCTURAL TYPES AND FRAMING SYSTEMS

**3.1.1** The following hull shell structural types (deck plating and bulkhead plating) are recommended ([refer to Fig. 3.1.1](#)):

- .1** single-skin construction shell:  
homogeneous FRP based on the same reinforcement material type;  
non-homogeneous FRP based on two (less frequent – three) different types of material, e.g. manufactured of glass fabric with different weaving and reinforcement schemes;  
hybrid FRP based on reinforcement materials of different chemical nature, e.g. glass fabric and carbon fiber ([refer to 1.2.2](#)).
- .2** sandwich construction shell with load-bearing layers manufactured of homogenous, non-homogeneous and hybrid FRP and expanded-type core, for which PVC and PUR foams are recommended.
- .3** sandwich construction shell with a core reinforced with reinforcement material layers. In such case, a lightweight mat is recommended as a core ([refer to 2.3.3.4](#)).

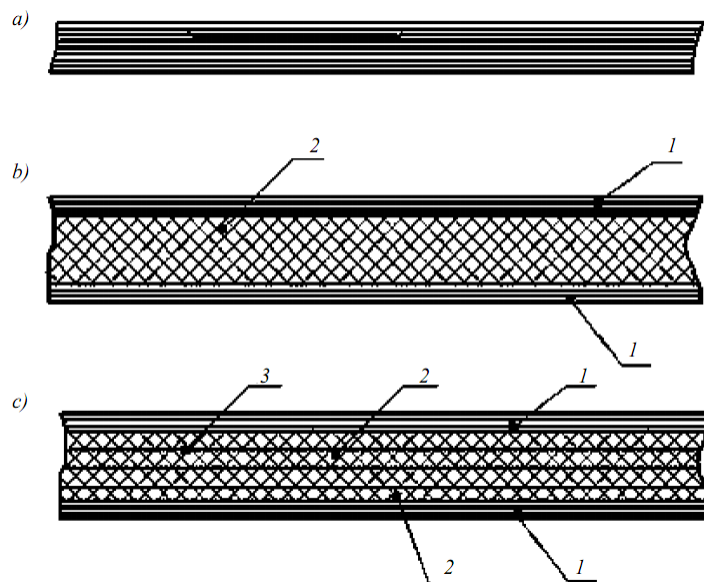


Fig. 3.1.1

Structural schemes of the hull shell (decks plating and bulkhead plating) manufactured of FRPs:  
a) single-skin construction shell; b) sandwich construction shell with expanded-type core; c) sandwich construction shell with a core reinforced layer by layer  
1 – load-bearing layers; 2 – core; 3 – reinforcement layers

**3.1.2** Application of sandwich construction for the hull shell may be permitted by the Register in case the mature manufacture procedure and proven quality performance control methods to ensure firm joint of all layers to form integral structure are available at the firm (manufacturer).

**3.1.3** The hull shell shall be stiffened, with the following framing systems used depending on mutual arrangement of members ([refer to Fig. 3.1.3](#)):

transverse framing system when all framing members are fitted in line with every frame, except for a centre girder ([refer to Fig. 3.1.3, a](#));

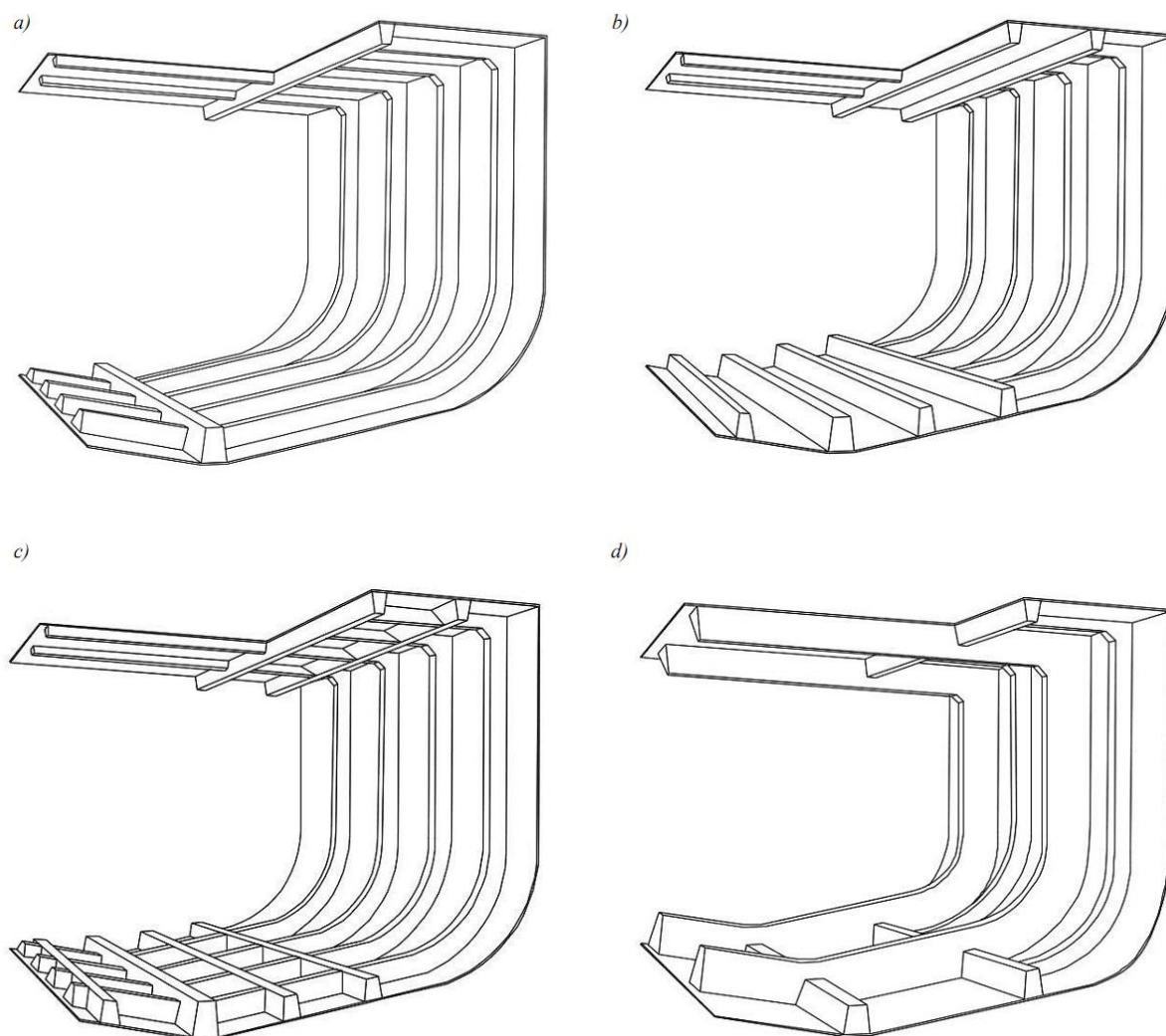


Fig. 3.1.3

Ship hull framing systems:

a) transverse framing system; b) mixed framing system with framing members fitted in way of bottom and upper deck along the hull; c) mixed framing system with continuous or intercostal transverse members in way of bottom and upper deck; d) mixed framing system with transverse deep members.

mixed framing system – transverse on sides and in way of bottom (upper deck) as follows:

with framing members fitted along the hull ([refer to Fig. 3.1.3, b](#));

mixed framing system with continuous or intercostal transverse members ([refer to 1.3.5, Fig. 3.1.3, c](#));

mixed framing system with transverse deep members ([refer to Fig. 3.1.3, d](#)).

In case of mixed framing system, transverse members in way of bottom shall be arranged in line with every frame.

**3.1.4** When selecting hull structural type of a ship, including its framing system, the following shall be considered:

purpose and size of a ship;

operating conditions;

requirements for the hull weight and necessity of ensuring its longitudinal and local strength and stiffness;

labour input in ship hull construction;

number of ships in a series, etc.

**3.1.5** For ships of 15 – 70 m in length, minimum spacing of a transverse framing considering the requirements of [1.3.4](#) shall be equal to:

for hulls with a single-skin shell – 500 mm;

for hulls with a sandwich shell – 1000 mm.

Transverse framing system shall be applied in the forepeak, and the above spacing shall be decreased to the following values:

for hulls with a single-skin shell – 400 mm;

for hulls with a sandwich shell – 800 mm.

**3.1.6** Selection of hull framing system and spacing values shall be substantiated by the designer based on longitudinal and local strength calculations taking into account the factors specified in [3.1.4](#). In such case, the recommendations mentioned below shall be considered.

Transverse framing system is recommended to apply with the following:

single-skin shell for ships of  $L \leq 20$  m in length;

sandwich shell for ships of  $L \leq 30$  m in length.

Mixed framing system with a single-skin or sandwich construction shell is recommended for ships of  $L \leq 30$  m in length. When selecting a shell structure, it shall be considered that sandwich construction shell as compared to a single-skin allows reducing the number of framing members and their intersections accordingly ([refer to 1.3.4](#)), as well as reducing weight of a structure considering the conditions enabling the implementation of the structure ([refer to 3.1.2](#)).

Mixed framing system with longitudinal arrangement of members in way of bottom with both single-skin and sandwich construction shell is recommended for ships, including high-speed craft of  $L = 15 \div 20$  m in length. In the latter case, redans may be used as framing members.

**3.1.7** Closed box section or its variety, trapezoidal section, shall be mainly for framing members. These sections consist of a core and its sheathing that forms a face plate and framing member webs that shall be tapered into flanges jointing the framing member to the hull shell (deck plating, bulkhead plating) ([refer to Fig. 3.1.7, a, b](#)).

The above-mentioned sections may not have a core, and their webs and face plate shall be performed over a former with flanges, or the latter may be made as a separate blank which is connected to the hull shell (deck plating, bulkhead plating) by means of moulding-in angles.

**3.1.8** Application of T-shaped and L-shaped sections is allowed when they are able to function as seating girders at the same time ([refer to Fig. 3.1.7, c, d](#)).

The stiffeners of these sections shall be connected to the hull shell (deck plating, bulkhead plating) by means of moulding-in angles.

**3.1.9** Recommendations on shell structures (deck plating, bulkhead plating) and the stiffeners of the sections specified, including reinforcement components and schemes of these elements are provided in [3.2.1 – 3.2.3](#).

### 3.2 HULL STRUCTURE

#### 3.2.1 Shell plating.

##### 3.2.1.1 Single-skin shell.

.1 woven roving and multiaxial fabrics shall be used for single-skin hull shell for ships of 15 — 70 m in length. When selecting type and grade of reinforcement material, the laying-up procedure of material and shell moulding technique using either contact or vacuum moulding techniques;

.2 for ships of 15 – 20 m in length, fabric may be laid both along and across the hull. Parallel shell reinforcement scheme  $[(0^\circ/90^\circ)]$  shall be used, with  $0^\circ$  direction (warp) positioned along the shell generatrix, or along its directrix. In the latter case, the breaking strength in  $90^\circ$  direction (weft) shall be not lower than the breaking strength in  $0^\circ$  direction (warp), in fabrics with  $(0^\circ/90^\circ)$  reinforcement;

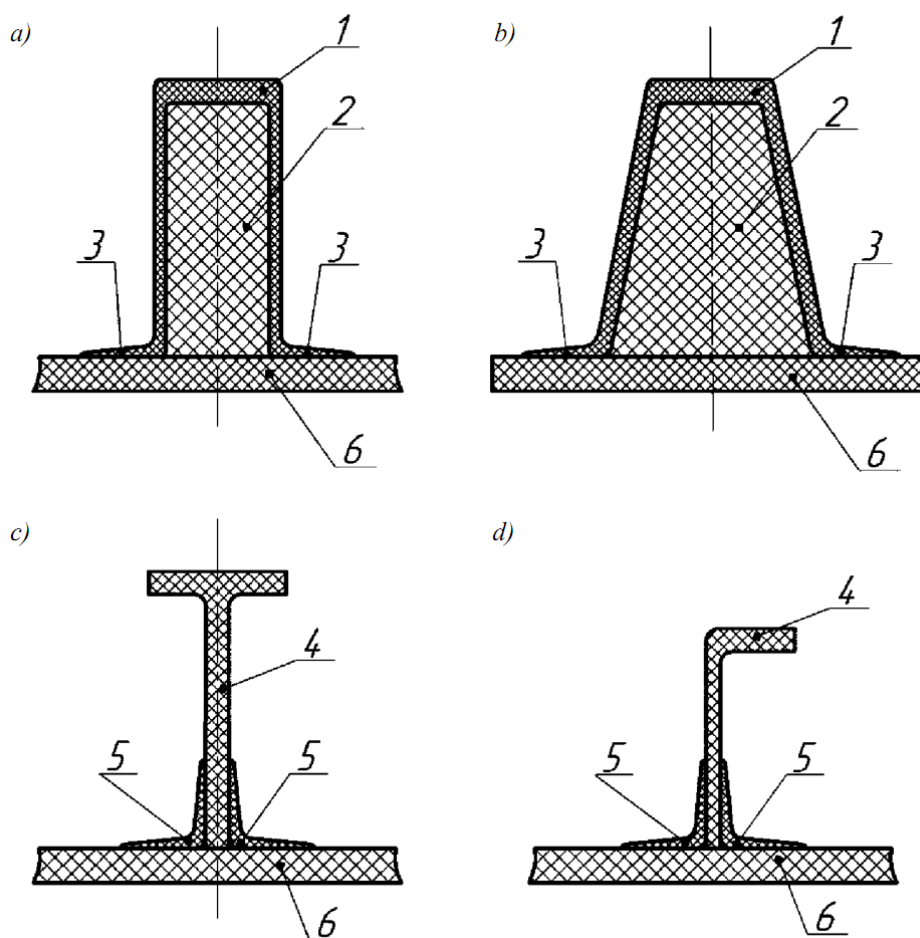


Fig. 3.1.7

Structural types of framing members:

a) closed box section; b) closed box section variety - trapezoidal section; c) T-shaped stiffener; d) L-section stiffener  
1 – section sheathing; 2 – core; 3 – flanges; 4 – framing member; 5 – moulding-in angles; 6 – shell (deck plating, bulkhead plating)

.3 for ships of 20 m in length, it is recommended to lay fabric blankets across the hull. In such case, parallel and diagonal reinforcement scheme  $[(0^\circ/+45^\circ/90^\circ/-45^\circ)]$  shall be applied. It may be implemented by using two types of fabric – biaxial with reinforcement

( $0^\circ/90^\circ$ ) and diagonal with reinforcement ( $+45^\circ/-45^\circ$ ), or based on quadriaxial fabric with 4 reinforcement directions ( $0^\circ/+45^\circ/90^\circ/-45^\circ$ );

.4 when two types of fabric with reinforcement ( $0^\circ/90^\circ$ ) and ( $+45^\circ/-45^\circ$ ) and similar surface density are used, the number of layers in the second fabric shall be determined based on the condition that the total thickness of its layers soaked in binder shall be equal to (0,4 — 0,45) of the shell thickness. In such case, two alternatives of layer arrangement over the thickness are available for these fabrics:

uniform arrangement, when fabric layers ( $0^\circ/90^\circ$ ) are uniformly alternated with diagonal fabric layers ( $+45^\circ/-45^\circ$ ), with 2 – 4 layers of the first fabric (depending on the shell thickness) shall be laid on outer surfaces of the shell;

packet arrangement, when fabric layers ( $0^\circ/90^\circ$ ) are assembled in packets arranged on outer surfaces of the shell, with fabric layers ( $+45^\circ/-45^\circ$ ) between them;

.5 when quadriaxial fabrics with reinforcement ( $0^\circ/+45^\circ/90^\circ/-45^\circ$ ) are used, the total surface density of the roving in reinforcement directions ( $0^\circ/90^\circ$ ) shall be approximately equal (up to 15 % difference) to that in directions ( $+45^\circ/-45^\circ$ );

.6 when moulding the shell, the first and last 2 – 4 fabric layers (depending on the shell thickness) arranged on its outer surfaces shall be laid up along butts (in warp) with at least 50 mm overlap, and along seams (in weft) – without overlapping. The overlap shall be performed from bow to aft. Other layers shall be laid up along butts and seams without overlapping (refer to Fig. 3.2.1.1.6).

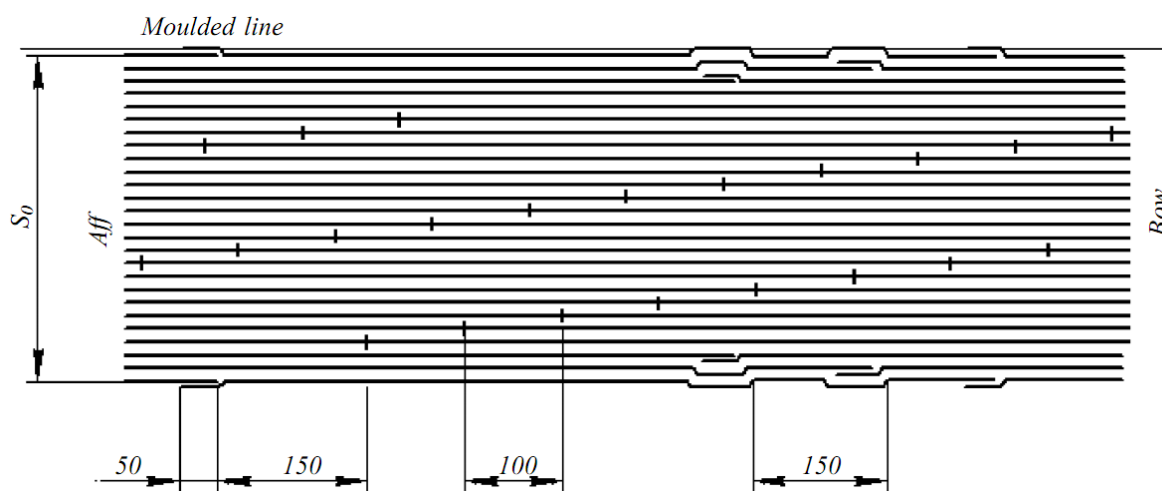


Fig. 3.2.1.1.6  
Scheme of a ship hull single-skin shell

Fabric butts and seams shall be spaced not closer than 100 mm apart from adjacent layers. Butts and seams are permitted to be coincident in one section after 5 layers at least;

.7 shell thickness  $s$  in the midship body shall be determined as the maximum of the two values  $s = \max(s_d, s_s)$ , where  $s_d, s_s$  = shell thickness determined according to the diagrams in Fig. 3.2.1.1.7-1 based on the specified requirements for stiffness and strength accordingly.

Minimum thickness  $s$  of the hull shell in bottoms and sides in the midship body shall not be lower than the values determined according to the diagrams in Fig. 3.2.1.1.7-3, depending on the ship length between perpendiculars  $L$ .

In the fore and after ends these thicknesses shall be increased by at least 20 %, and for high-speed craft subject to high loads due to slamming, the shell thickness in the fore end shall be increased by at least 40 %.

Selected thicknesses of the hull shell shall be confirmed by the designer based on longitudinal and local hull strength calculations;

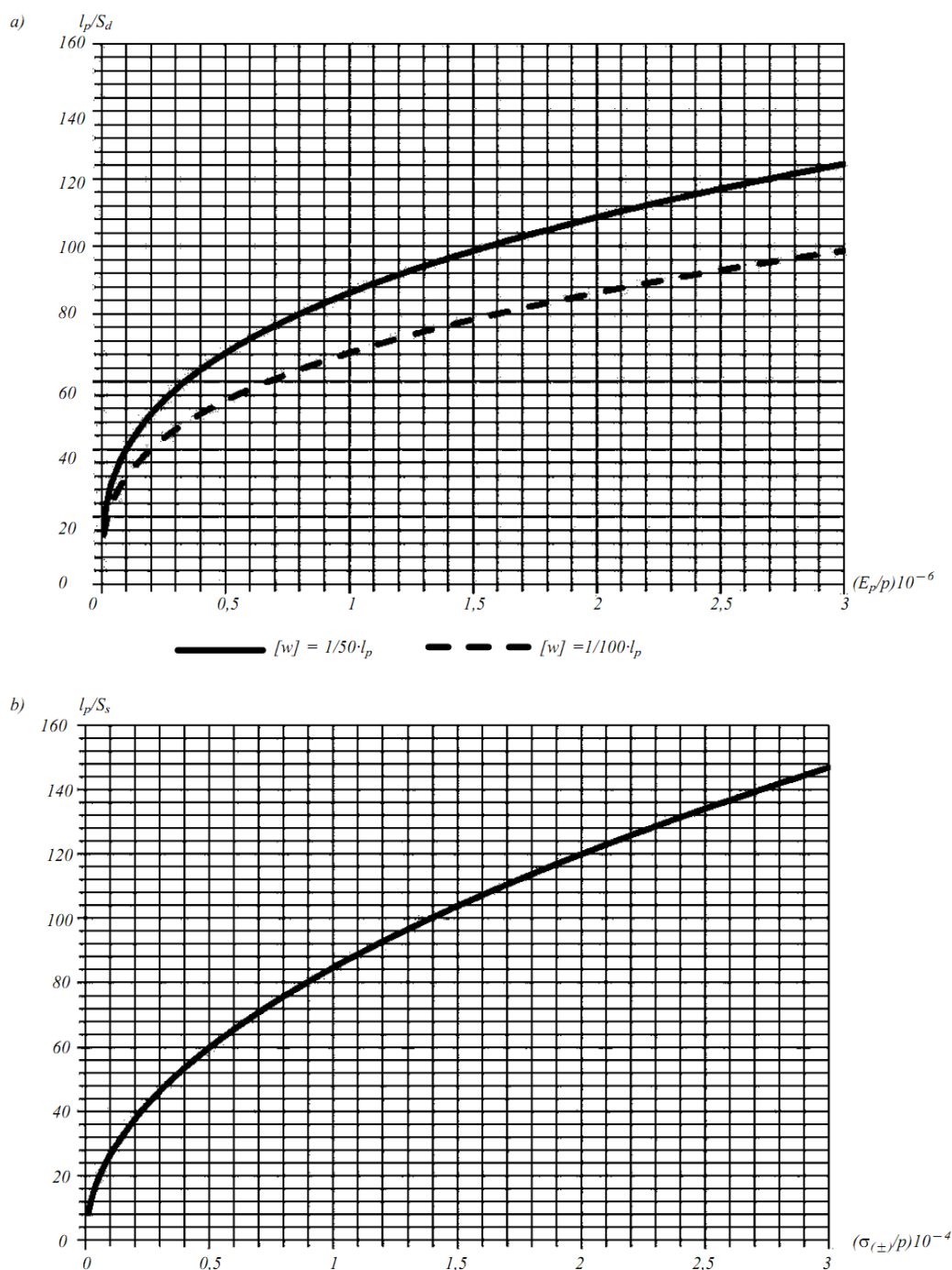


Fig. 3.2.1.1.7-1

Dependency diagrams of the maximum supporting contour length  $l_p$ , in m, of the laminate ratio to its thickness  $s_d$ , ( $s_s$ ), in m, and the ratio of laminate material properties  $E_p$ ,  $\sigma_{(\pm)}$ , in MPa, to design pressure  $p$ :

$E_p$  = design Young's modulus of shell material, in MPa;

$\sigma_{(\pm)}$  = minimum ultimate strength of shell material, in MPa.

$l_p$  = supporting contour length of a laminate determined in accordance with [Fig. 3.2.1.1.7-2](#).

a – requirements for permissible deflections  $[w] = 1/50 \cdot l_p$ ,  $[w] = 1/100 \cdot l_p$ ; b – requirements for permissible stresses  $[\sigma] = 0,36 \sigma_{(\pm)}$

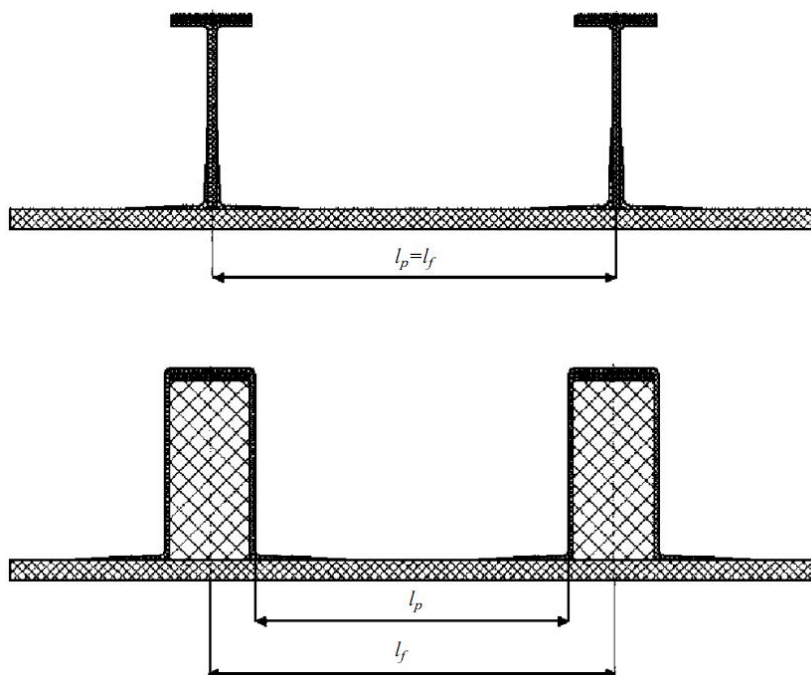


Fig. 3.2.1.1.7-2

Determination of the supporting contour length with framing members of different sections:  $l_f$  = spacing

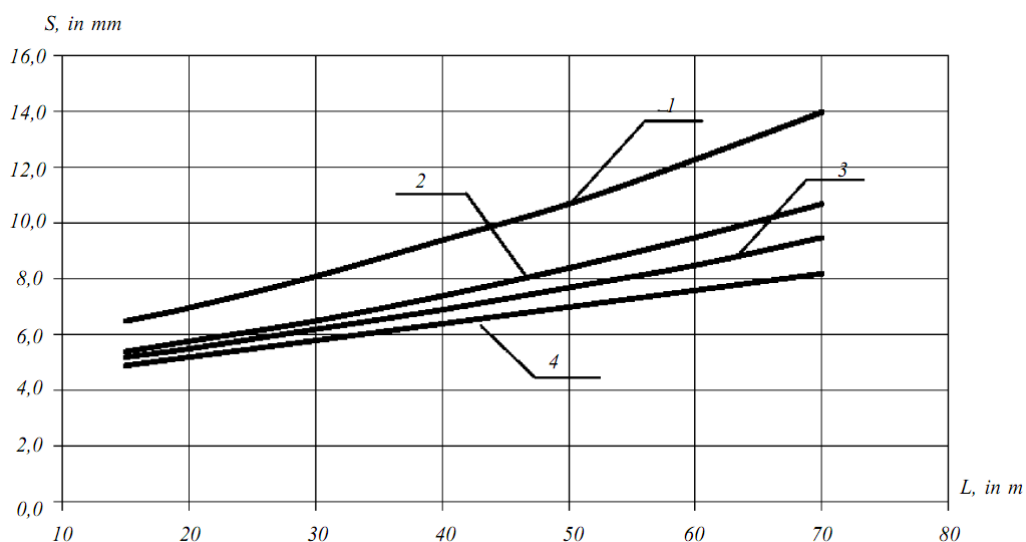


Fig. 3.2.1.1.7-3

Dependence of the minimum thickness of single-skin structures of the hull shell, deck and bulkhead plating manufactured of glass-reinforced plastic on the ship length ( $L$  = length between perpendiculars):

1 – bottom shell plating; 2 – side shell plating; 3 – upper deck; 4 – bulkheads

**.8** shell thickness shall be increased gradually by adding fiber layers inside the packet of basic continuous layers, whereas reduction of the thickness requires removal of some layers inside the packet. It is recommended to alternate layers that are removed or added with continuous layers.

$$\Delta \geq 15 \times (S_1 - S_0)$$

The diagram shows a stepped profile. The horizontal segments have a length of  $c$ , and the condition  $c \geq 50$  is specified. The vertical segments have a height of  $S_0$  and  $S_1$ . The total width of the profile is  $\Delta$ .

1. for load-bearing layers of the sandwich shell, it is recommended to apply the same reinforcement materials and reinforcement schemes as for the single-skin shell (refer to 3.2.1.1.1 – 3.2.1.1.5).

.2 PVC foams and mats may be applied as a core ([refer to 2.3.3.4](#)). When higher strength and thickness are required, they may be reinforced with fabric, preferably of woven roving type ([refer to Fig. 3.1.1 b, c](#));

.3 in case of an expanded-type foam, the following foam plastic densities are recommended for the hull and upper deck shell:

for ships of more than 20 m in length – 60 – 80 kg/m<sup>3</sup>;

for ships of 20 – 40 m in length – 80 – 120 kg/m<sup>3</sup>;

for ships over 40 m in length – 120 – 200 kg/m<sup>3</sup>.

The specified recommendations are applicable to the listed structural members beyond reinforcement and joint areas (plate keel, sheerstrake, joint of the side to the deck etc.). Recommendations for selection of expanded-type foam densities for these areas are specified below;

.4 thickness of load-bearing layers of the bottom and side sandwich shells shall be determined according to the diagrams specified in [Fig. 3.2.1.2.4-1](#) as the maximum value of  $\delta_d$ ,  $\delta_s$ , determined in accordance with the conditions for compliance with the requirements for stiffness and strength accordingly. In this case, core thickness  $2h$  is recommended to be assumed at least 10 thicknesses of the load-bearing layer ( $2h \geq 10\delta$ ) in the first approximation.

The thickness of the core manufactured of the fabric-reinforced lightweight mat is assumed equal to  $2h \geq 6\delta$ .

In such case, the minimum thickness of load-bearing layers of the shell shall not be less than that specified in diagrams specified in [Fig. 3.2.1.2.4-2](#), depending on the hull length between perpendiculars  $L$ .

In the fore and after ends the thickness of load-bearing layers determined according to these diagrams shall be increased by at least 30 %. If the hull weight is restricted, it is allowed to increase the thickness of the outer load-bearing layer only;

.5 the plate keel in a sandwich shell shall be moulded by thickening of the inner load-bearing layer and/or by filling the core with an aggregate of the higher density as compared to that of the basic shell ([refer to Fig. 3.2.1.2.5](#)).

The inner load-bearing layer thickening is performed by moulding of additional fabric layers or by adding these layers between basic fabric layers forming this layer.

Application of thickening technique, type of fabrics used for this purpose, and the requirements for overlapping of additional fabric layers and mutual arrangement of their butts and seams shall be determined in accordance with the provisions of [3.2.1.1.9 – 3.2.1.1.11](#);

.6 inner load-bearing layer thickness  $\delta_2$  at the plate keel area is assumed equal to  $\delta_{PK} = 1,5\delta_2$ , whereas its width  $B_{PK} = 5s$ , where  $s$  is a total sum of the sandwich shell beyond the thickened area ([refer to 3.2.1.2.4](#)). The specified geometric parameters may be corrected based on the results of strength calculations that may also require increasing the outer load-bearing layer thickness  $\delta_1$ ;

.7 sheerstrake in the sandwich shell is recommended to be moulded using the same procedure as for the plate keel – by thickening the inner load-bearing layer and/or adding filler of higher density to the core. Reinforcement scantlings for the sheerstrake plating are selected according to the recommendations for the plate keel specified in [3.2.1.2.6](#).

### **3.2.2 Plating of decks and platforms.**

#### **3.2.2.1 Single-skin platings**

.1 single-skin platings are recommended for decks and platforms with heavy equipment fitted and that requires to be fastened to the shell and its supporting members. Such decks include cargo decks that accommodate the crane equipment and cargoes;

.2 for single-skin platings, multiaxial fabrics and infusion moulding technique are recommended.

For deck and platform platings of ships of up to 20 m in length it is allowed to apply biaxial fabrics with reinforcement ( $0^\circ/90^\circ$ ), and combination products<sup>1</sup> based on these fabrics laid either along or across the hull, depending on the reinforcement direction considered to be stronger.

For ships of more than 20 m in length, single-skin platings shall be based on quadriaxial fabrics with reinforcement ( $0^\circ/+45^\circ/90^\circ/-45^\circ$ ), or from a combination of two fabrics ( $0^\circ/90^\circ$ ) and ( $+45^\circ/-45^\circ$ ), considering the requirements of [3.2.1.1.4](#). When moulding laminate, these fabrics (in  $0^\circ$  direction), may be laid both along and across the hull.

For inner (intermediate) decks and platforms, it is allowed to apply biaxial fabrics, as well as combination products on their basis;

**.3** upper deck plating thickness and its minimum permissible value shall be determined according to [3.2.1.1.7](#).

The plating thickness of inner (intermediate) decks and platforms may be reduced by 10 – 20 % relative to that of the upper deck determined in accordance with the diagram provided, for specified length  $L$ ;

**.4** when moulding the upper deck platings, the first and last two fabric layers arranged on its outer surfaces shall be laid up along butts with at least 50 mm overlap, and along seams – without overlapping. Other layers shall be laid up along butts and seams without overlapping.

Fabric butts and seams shall be spaced not closer than 100 mm apart from adjacent layers. Butts and seams are permitted to be coincident in one section after 5 layers at least.

In laminates of inner (intermediate) decks and platforms, it is allowed to lay fabric layers along butts and seams without overlapping;

**.5** deck stringer and other reinforcements in deck and platform plates may be moulded by adding fabric layers on the packet of basic layers forming the laminate during its manufacture by means of infusion technique. In this case, the recommendations considering the overlapping of additional layers and thickness tapering specified in [3.2.1.1.8](#) and [3.2.1.1.9](#) shall be followed;

**.6** thickness and width of a deck stringer, as well as its thickness tapering, are recommended to be assumed the same as for the sheerstrake ([refer to 3.2.1.1.12](#)).

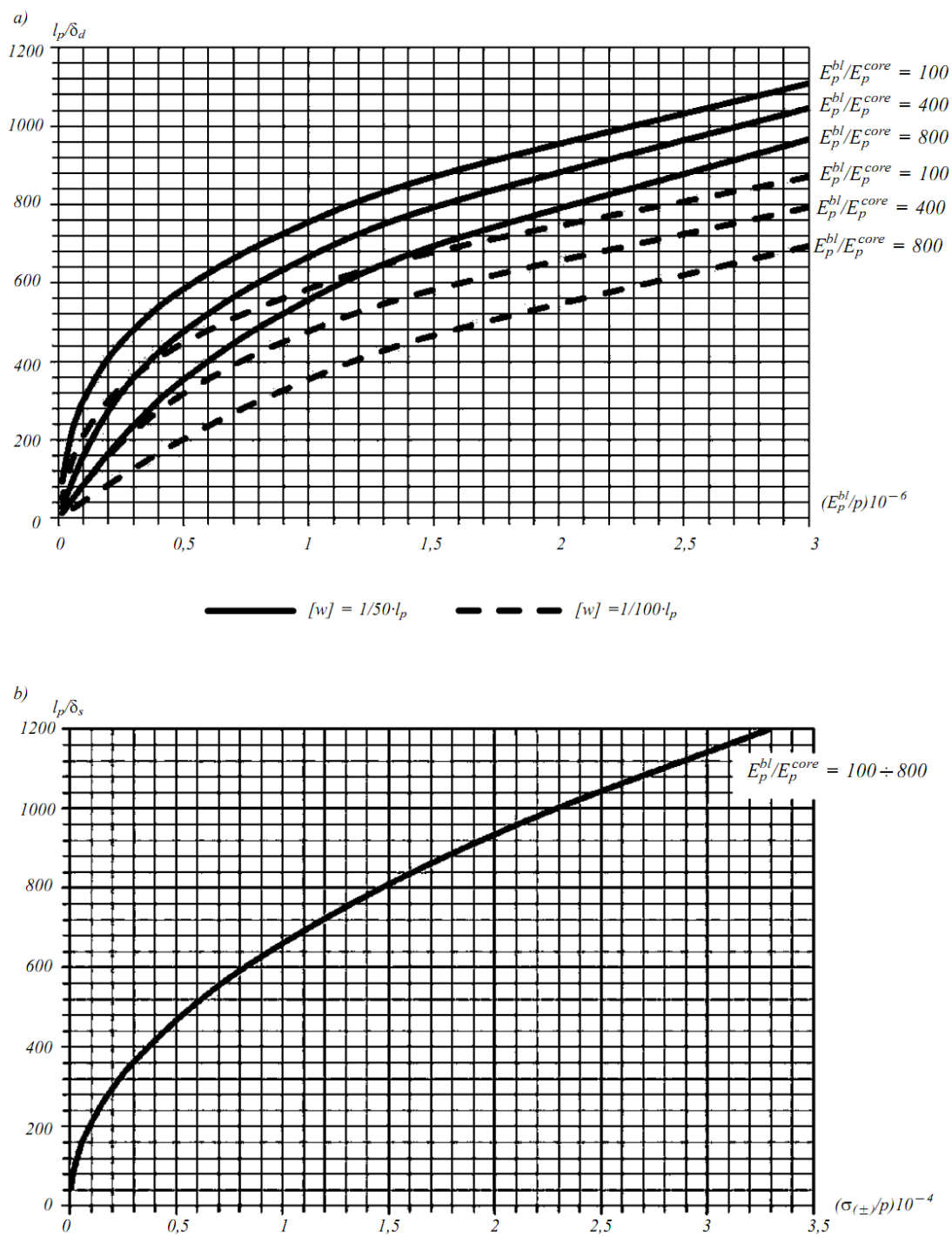
Woven roving or biaxial fabrics with reinforcement ( $0^\circ/90^\circ$ ) and increased strength in  $0^\circ$  direction are recommended as a reinforcement material when moulding a deck stringer;

**.7** deck and platform platings subject to intense wear shall be increased in thickness by straps of 2 mm, or protection coating shall be applied;

**.8** accepted thicknesses of deck and platform plates, and that of the deck stringer plate shall be specified based on the calculation results of strength and buckling strength of hull's structural members.

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<sup>1</sup> Combination product means a fabric jointed with a mat to form a single blanket.



Dependency diagrams of the maximum supporting contour length  $l_p$ , in m, of the sandwich laminate ratio to thickness of its load-bearing layers  $\delta_d$ , ( $\delta_s$ ), in m, and the ratio of laminate load-bearing layers' material properties  $E_p^{bl}$ ,  $\sigma_{(\pm)}^{bl}$  in MPa, to design pressure  $p$  (at  $2h = 10\delta$ ):

$E_p^{bl}$  – design Young's modulus of load-bearing layer material of sandwich laminate;  $E_p^{core}$  – design Young's modulus of the sandwich laminate's core material, in MPa;  $\sigma_{(\pm)}^{bl}$  – minimum ultimate strength of load-bearing layer material, in MPa.

a – requirements for permissible deflections  $[w] = 1/50 \cdot l_p$ ,  $[w] = 1/100 \cdot l_p$ ; b – requirements for permissible stresses  $[\sigma] = 0,36\sigma_{(\pm)}$ .

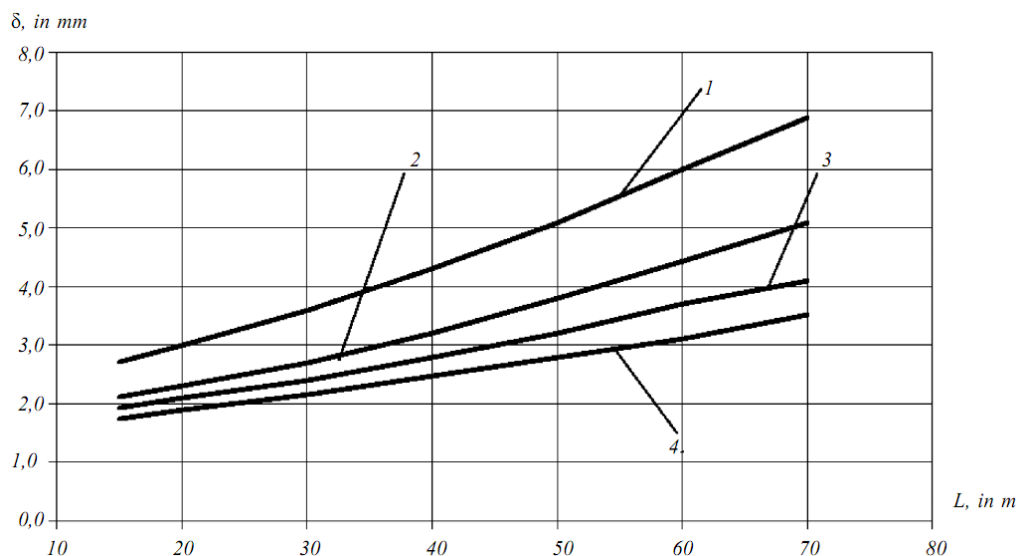


Fig. 3.2.1.2.4-2

Dependence of the minimum thickness of load-bearing layers of hull shell sandwich structures, deck and bulkhead plating on the ship length ( $L$  – length between perpendiculars):  
 1 – bottom plating; 2 – side plating; 3 – upper deck; 4 – bulkheads

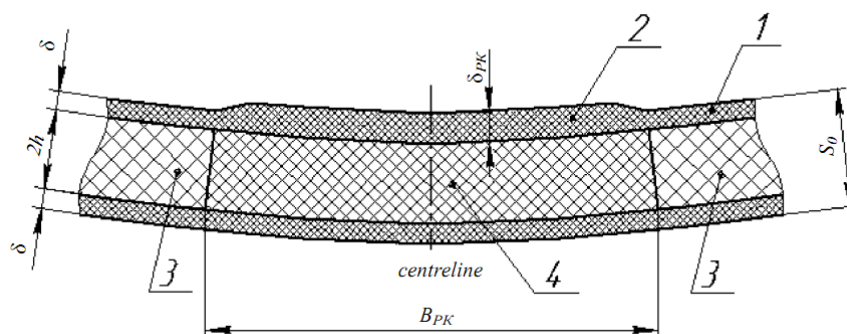


Fig. 3.2.1.2.5

Sandwich shell structure at the plate keel area

1 – load-bearing layers; 2 – thickening of the inner load-bearing layer; 3 – core (foam plastic);  
 4 – core (foam plastic of increased density)

### 3.2.2.2 Sandwich platings

**.1** for load-bearing layers of the deck and platform sandwich plates, it is recommended to apply the same reinforcement materials and reinforcement schemes as for single-skin platings ([refer to 3.2.2.1.2](#)).

An infusion technique is recommended for manufacturing these structures;

**.2** PVC foams, PUR foams or mats may be used as a core in deck and platform sandwich plates ([refer to 2.3.3.4](#)). When higher strength and thickness are required, they may be reinforced with fabric, preferably of woven roving type ([refer to Fig. 3.1.1, c](#));

**.3** plate thickness of upper deck load-bearing layers and its minimum permissible value shall be determined according to [3.2.1.2.4](#).

It is recommended to assume the thickness of a core filled with foam plastic to be at least 10 thicknesses of the load-bearing layer at the first approximation, while for the fiberglass-reinforced mat core – at least its 5 thicknesses;

.4 recommendations on selecting the foam plastic density for the upper deck with an expanded core are specified in [3.2.1.2.3](#).

For inner (intermediate) decks and platforms, the foam plastic density in the core may be reduced by 10 – 20 kg/m<sup>3</sup> compared to the foam plastic selected for the hull shell but it shall be at least 40 kg/m<sup>3</sup>.

In such case, it shall be taken into account that in places of joint to other structures (sides, bulkheads, superstructure sides and ends, etc.) and in places of equipment fastening, the expanded foam density shall be increased to bear transverse local forces. Recommendations on selection of the foam plastic density for a core in deck and platform sandwich plates in such places are specified in [3.2.4 – 3.2.7](#);

.5 structural orthotropic filler consisting of PVC foam or PUR foam with density of at least 35 – 50 kg/m<sup>3</sup> reinforced with a corrugated element may be applied as a core in deck sandwich plates ([refer to Fig. 3.2.2.2.5](#));

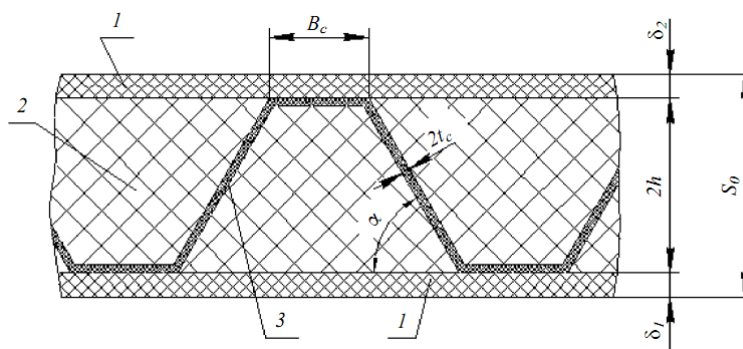


Fig. 3.2.2.2.5

Scheme of a deck sandwich laminate (bulkhead plating) with a corrugated element and foam plastic in a core  
1 – load-bearing layers; 2 – foam plastic; 3 – corrugated element

.6 parameters of a corrugated element at the first approximation shall be assumed equal to:

inclination angle of a corrugated element web  $\alpha = 45^\circ - 55^\circ$ ;

corrugated element thickness  $2t_c = (0,1 - 0,3)\delta$ , but at least 0,2 mm;

flange width  $B_c = (2 - 4)\delta$ ;

core width  $2h \geq 10\delta$ .

In such case, the corrugated element generatrix shall be directed along the ship hull, except when the transverse stiffness of the deck skin requires increasing;

.7 deck stringer and other reinforcements in deck and platform sandwich plating shall be formed by increasing the thickness of load-bearing layers and/or increasing the foam plastic density in the core ([refer to 3.2.1.2.5](#)). The load-bearing layers are thickened by laying additional fabric layers on basic layers forming load-bearing layers of a plate;

.8 width and thickness of the inner load-bearing layer of the deck stringer, as well as the core density are recommended to be the same as that of the sheerstrake in the hull sandwich shell ([refer to 3.2.1.2.7](#)). If necessary, the thickness of the outer layer of the upper deck at the deck stringer area may be also increased;

.9 where sandwich to single-skin transition is required in the deck, it shall be gradual as possible ([refer to Fig. 3.2.2.2.9](#)). The tapering length shall be selected based on condition  $l_{tap} \geq 5(s_s^2 - s_s^1)$ , where  $s_s^2$ ,  $s_s^1$  is the thickness of sandwich and single-skin areas of the deck laminate accordingly. Where  $s_s^1 > 2\delta$ , the lacking thickness shall be made up by laying

additional fiber layers to load-bearing layers, with their thickness gradually increased and selected reinforcement scheme maintained;

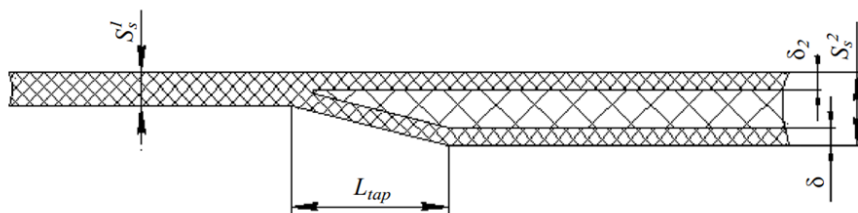


Fig. 3.2.2.2.9

Single-skin to sandwich transition of the deck plating

.10 deck parts subject to intense wear shall be protected according to the requirements of [3.2.2.1.7](#).

### 3.2.3 Bulkhead platings.

#### 3.2.3.1 Single-skin plating.

.1 plating of watertight bulkheads shall be single-skin where they carry heavy mechanisms and equipment that require secure and reliable fastening to the plating and bulkhead stiffeners.

.2 reinforcement materials, reinforcement composition and schemes for single-skin platings are recommended to be assumed the same as for single-skin deck platings (refer to [3.2.2.1.2](#) and [3.2.2.1.4](#)). Fabrics ( $0^\circ$  direction) shall be laid vertically (relative to  $0^\circ$  direction). It is allowed to lay fabrics along butts and seams without overlapping;

.3 minimum thickness of bulkhead platings is determined from the diagram in [Fig. 3.2.1.1.7-3](#), depending on ship length between perpendiculars  $L$ .

Accepted thickness of bulkhead platings shall be specified based on the results of strength and bucking strength calculations;

.4 procedure of bulkhead plating thickening shall be the same as for deck plating – by adding fabric layers on the packet of basic layers forming the plating when it is manufactured using the infusion technique, according to the provisions specified in [3.2.2.1.5](#).

#### 3.2.3.2 Sandwich plating.

.1 recommendations for selection of fabrics and reinforcement schemes for load-bearing layers of watertight bulkhead platings of sandwich construction are similar to those specified in [3.2.3.1.2](#);

.2 core in sandwich bulkhead platings may be formed as in sandwich deck laminates, using foam plastic or mat reinforced with fiber layers, or consist of a corrugated element with foam plastic in a space between corrugations (refer to [3.2.2.2.2](#) and [3.2.2.2.5](#));

.3 minimum thickness of bulkhead plating load-bearing layers is determined from the diagram in [Fig. 3.2.1.2.4-2](#), depending on ship length between perpendiculars  $L$ .

It is recommended to assume the thickness of a core filled with foam plastic to be at least 10 thicknesses of the load-bearing layer at the first approximation, while for the fiber-reinforced mat core – at least its 5 thicknesses;

.4 in case of the expanded-type foam, the foam plastic density in the core may be reduced by 10 – 20 kg/m<sup>3</sup> compared to the foam plastic selected for the upper deck but it shall be at least 40 kg/m<sup>3</sup>;

.5 for structural orthotropic filler, the foam plastic density and corrugated element parameters shall be determined as the first approximation in accordance with the provisions of [3.2.2.2.5](#) and [3.2.2.2.6](#). In such case, generatrix of a corrugated element shall be vertically directed;

.6 reinforcements in sandwich bulkhead platings shall be formed in deck plating, according to the provisions of [3.2.2.2.7](#).

### 3.2.4 Framing members.

3.2.4.1 The stiffening framing members of the hull shell, deck (platform) plating, as well as bulkhead platings shall be generally moulded in accordance with [3.1.7](#), using a closed box section.

3.2.4.2 The following alternatives of the section sheathing are possible:

.1 reinforcing fabric layers are laid on the surface of a core fitted on the shell (deck plating and bulkhead plating), continuously along the section profile simultaneously forming flanges that connect a framing member to the shell (plating) (refer to Fig. 3.2.4.2.1, a).

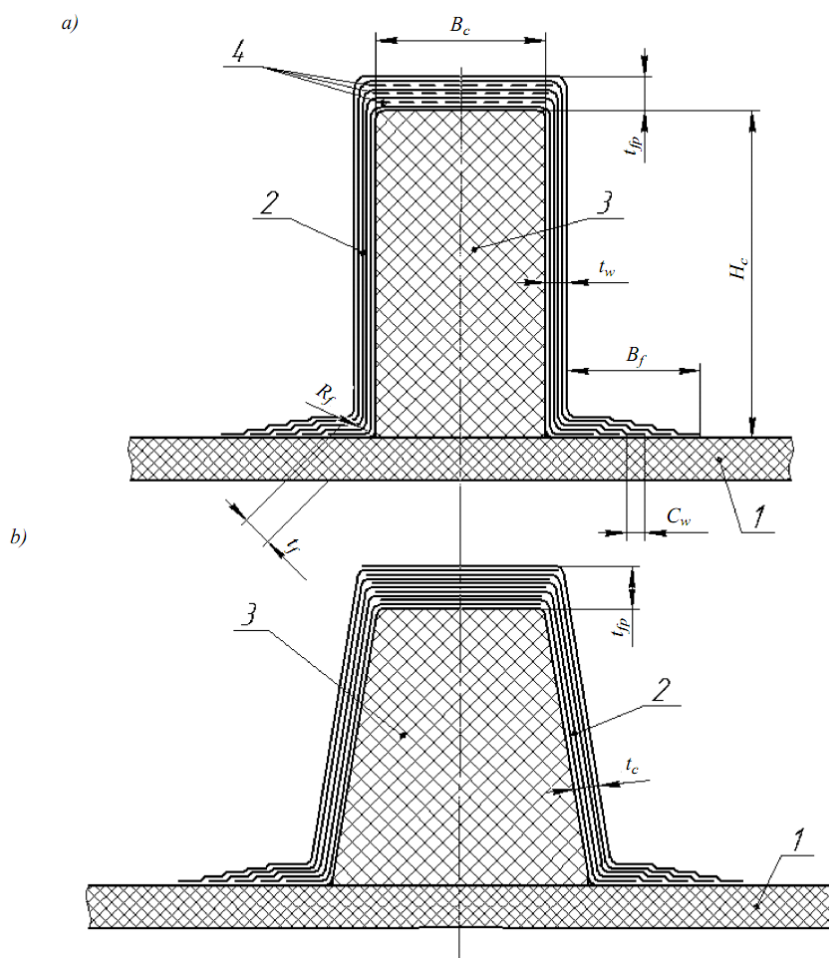


Fig. 3.2.4.2.1

Design of a closed box framing section with continuous sheathing along the stiffener contour (a) and with sheathing layers cut and overlapped on a face plate (b):

1 – shell (deck plating and bulkhead plating); 2 – stiffener sheathing; 3 – core; 4 – additional reinforcement of a face plate

A face plate shall be reinforced by adding fabric or tape layers (laid along the framing member) between basic sheathing layers, or by assembling additional layers into a packet which is placed on a core followed by sheathing with basic layers;

.2 basic fabric layers forming the core sheathing are cut and laid when forming a face plate with an overlap, to alternate with each other successively while being laid from one and

other section sides. In this case, a face plate contains twice as many fiber layers as compared to webs (refer to Fig. 3.2.4.2.1, b). A face plate may be also reinforced by adding fabric layers;

**.3** a stiffener is moulded from premanufactured core with webs matted on both webs. Such pre-moulded stiffener is fitted on the shell (deck plating and bulkhead plating) and connected to by means of moulding-in angles.

A face plate is moulded as a strap, with its layers matted on the pre-moulded stiffener side and bent around the section web, each next layer overlapping a preceding one (refer to Fig. 3.2.4.2.3). A face plate may be also reinforced additionally with fabric or tape layers.

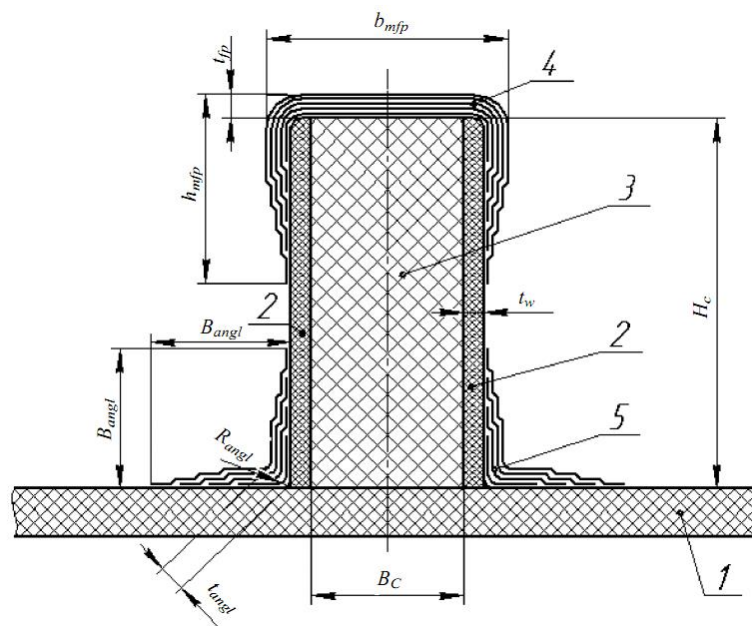


Fig. 3.2.4.2.3

Design of a closed box section of framing member with a face plate as a matted-on strap bent around section webs:  
1 – shell (deck plating and bulkhead plating); 2 – section webs; 3 – filler (core); 4 – strap (face plate);  
5 – matted-in angles

**3.2.4.3** In all cases, a core is placed on the shell (deck plating and bulkhead plating) via adhesive. To form rounded flanges in section angles or moulding-in angles of the relevant radius, adhesive is also used, which may be filled with microspheres or chops to increase its viscosity, or special pastes.

**3.2.4.4** For a filler (core) of a closed box section, it is recommended to use foam plastics of PVC type (refer to 2.3.3.6 and 2.3.3.8) of the density not lower than the one recommended for the hull shell of a ship with the specified length (refer to 3.2.1.2.3).

**3.2.4.5** The sheathing of a closed box section shall be based on woven roving and multiaxial fabrics.

Additional layers between basic fabrics of the sheathing or a packet to reinforce a face plate of the framing member (refer to 3.2.4.2) shall be also made of woven roving or multiaxial fabrics with reinforcement ( $0^\circ/90^\circ$ ) of increased strength in  $0^\circ$  direction positioned along the framing member, or of one-directional tapes with reinforcement ( $0^\circ$ ).

**3.2.4.6** If relative depth of the framing member  $H_c/l_p < 1/10$  where  $H_c$  is the section core depth,  $l_p$  is the design length of the framing member span, then fabrics with reinforcement ( $0^\circ/90^\circ$ ), with  $0^\circ$  direction laid along the framing member, shall be used in the sheathing. In such case, fabric strength in this direction shall be at least not lower than in  $90^\circ$  direction.

For the relative depth of the framing member  $H_c/l_p \geq 1/10$ , the reinforcement scheme of the closed box section sheathing shall be parallel and diagonal that requires quadriaxial

fabrics with reinforcement ( $0^\circ/+45^\circ/90^\circ/-45^\circ$ ), or a mix of fabric ( $0^\circ/90^\circ$ ) and diagonal fabric ( $+45^\circ/-45^\circ$ ) in parts of equal thickness, with  $0^\circ$  direction laid along the member, to be applied. In the first and last 1 – 2 sheathing layers, fabric ( $0^\circ/90^\circ$ ) shall be used, other layers shall consist of uniformly alternating layers of the first and diagonal fabrics ( $+45^\circ/-45^\circ$ ).

Seams of fabric platings in the sheathing and cuts on section webs, that are performed in curvilinear framing members where necessary, shall be spaced not closer than 80 mm apart. Seams and cuts are permitted to be coincident in one section after 3 layers at least.

**3.2.4.7** Scantlings of closed box section elements of framing members shall be selected at the first approximation from the following:

$$B_c/H_c = 0,35 \div 0,5; t_w/H_c = 0,03 \div 0,05; t_{fp}/t_w = 1,8 \div 2,2;$$

$$1,2B_c \geq b_f \geq 10t_w \geq 30 \text{ mm}; t_f = t_w$$

where  $B_c, H_c$  = width and depth of the section core, accordingly;  
 $t_{fp}, t_w$  = thicknesses of the face plate and webs accordingly;  
 $b_f$  = width of flanges;  
 $t_f$  = flange thickness in transition radius  $R_f$  to webs ([refer to Fig. 3.2.4.2.1, a](#)).

The value  $B_c$  for the trapezoidal section corresponds to the length of the trapezoid median, and it may be assumed equal to  $B_c/H_c = 0,7 \div 1,0$ , when the ratio of the shorter and longer base shall be approximately  $0,6 \div 0,7$ .

**3.2.4.8** For the closed box section of framing members ([refer to Fig. 3.2.2.2.9](#)), parameters of moulding-in angles shall be selected based on the following:

$$t_{angl} \geq 0,5s_p; b_{angl} \geq 15t_{angl}; R_{angl} = (1,0 \div 1,2)t_{angl},$$

where  $s_p = (t_w + s_{shell}/2)/2$ ,  
 $s_{shell}$  = thickness of the single-skin shell (deck and bulkhead plating);  
 $s_{shell} = 4\delta$  – for the sandwich shell (deck and bulkhead plating);  
 $\delta$  = average thickness of load-bearing layers.

The amount of the strap bending that forms a face plate around section webs is recommended to be assumed equal to  $H_c - b_{angl} > h_{mfp} \geq 5t_c$  where  $b_{mfp} = B_c + 2(t_c + t_s)$  ([refer to Fig. 3.2.4.2.3](#)).

**3.2.4.9** T-shaped and L-shaped sections, the installation of which are appropriate in the areas with the heavy equipment ([refer to 3.1.8](#)), are formed by bending the half of web thickness from each side around the face plate. The framing member shall be connected to the shell (deck plating, bulkhead plating) by means of with moulding-in angles ([refer to Fig. 3.2.4.9](#)).

**3.2.4.10** T-shaped sections shall be made of woven roving and multiaxial fabrics, with one-directional bands used for the face plate reinforcement.

**3.2.4.11** Depending on the relative depth of the T-shaped section web  $H_c/l_p$ , the web reinforcement scheme may be  $[(0^\circ/90^\circ)]$  or  $[(0^\circ/+45^\circ/90^\circ/-45^\circ)]$  ([refer to 3.2.4.6](#)). The portion of the face plate thickness which is matted on bent parts of the web is made of fabrics with reinforcement ( $0^\circ/90^\circ$ ) with increased strength in  $0^\circ$  direction and/or one-directional tapes ( $0^\circ$ ).

**3.2.4.12** Scantlings of T-section elements of framing members shall be selected at the first approximation based on the following ([refer to Fig. 3.2.4.9](#)):

$$B_{fp}/H_w = 0,35 \div 0,5; t_w/H_w = 0,04 \div 0,08; t_{fp}/t_w = 2,0 \div 2,5.$$

Parameters of moulding-in angles shall be selected in accordance with the requirements of [3.2.4.8](#).

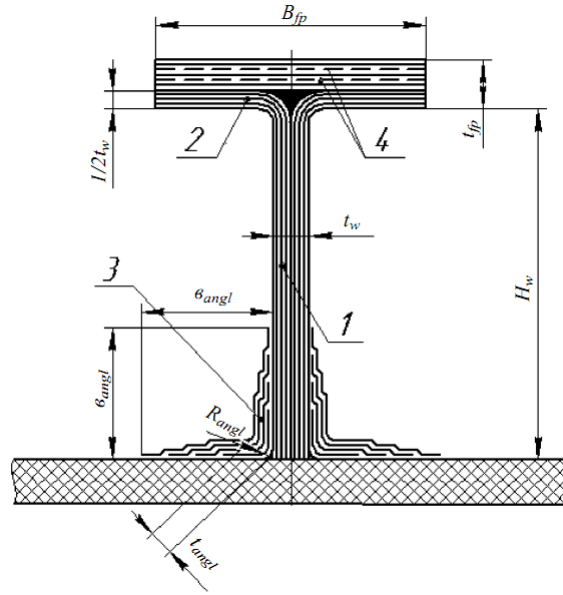


Fig. 3.2.4.9

Design of T-shaped section of framing members

1 – section web; 2 – face plate; 3 – moulding-in angles; 4 – additional reinforcement of a face plate

**3.2.4.13** Scantlings of framing member elements shall be determined from the required bending stiffness using the following formula:

$$D_{11} = \sum_{i=1}^n (E_1^{(i)} F_i z_i^2 + I_i) - e^2 \sum_{i=1}^n E_1^{(i)} F_i z_i^2, \quad e = \left( \sum_{i=1}^n E_1^{(i)} F_i z_i^2 \right) / \left( \sum_{i=1}^n E_1^{(i)} F_i \right)$$

where  $E_1^{(i)}$  = Young's modulus of material of the  $i$ -th member section element along the framing member longitudinal axis;  
 $F_i$  = cross-sectional area of the  $i$ -th element;  
 $z_i$  = distance of the  $i$ -th element's center of gravity from the reference axis.

For members with the relative depth of the section  $H_c/l_p < 1/10$ , the bending stiffness  $D_{11}$  is determined as the maximum of the values:

$$D_{11} = \max(D_{11}^d, D_{11}^s);$$

$$D_{11}^d = \mu \frac{M_p l_p}{k_w}, \quad D_{11}^s = E_1^{(i)} \frac{M_p z_i}{k_\sigma \sigma_{11}^{(i)}}$$

where  $M_p$  = design bending moment;  
 $\sigma_{11}^{(i)}$  = minimum ultimate strength of material of the  $i$ -th element (tensile strength or compression strength along the framing member);  
 $\mu$  = numerical factor depending on type of load and fastening of framing member support sections ([refer to Table 3.2.4.13](#));  
 $k_w, k_\sigma = k, k_n$  – factors in accordance with [5.3.4](#) and [5.3.7](#).

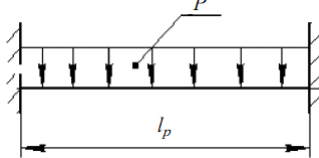
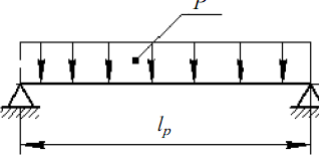
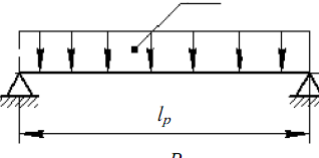
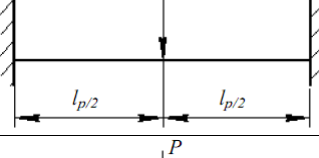
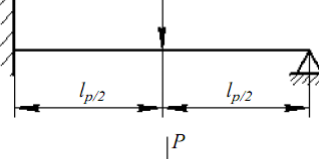
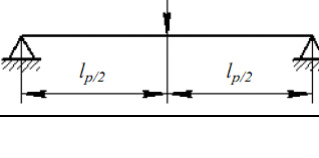
The formulae to determine the stress-strain behavior and shear capacity of framing members are specified in [Appendix 1](#).

**3.2.4.14** Longitudinals (centre girder, stringers, deck girders) shall be continuous over the part of the ship length, which shall be at least  $0,6L$ . In this case, longitudinals shall be continuous through transverse bulkheads and transverse deep members (floors and beams) (refer to Fig. 3.1.3, d).

**3.2.4.15** Where the longitudinal framing member passes through the bulkhead, an opening therein shall exceed the section scantlings by 4 – 5 mm.

Where the bulkhead shall be watertight, gaps between the framing member and an opening shall be filled in with filler or paste based on chopped fibers and binder. After gaps are filled in, angle straps shall be matted on to connect the framing member to the bulkhead, and then straps to connect its face plate to the web and to overlap the first straps (refer to Fig. 3.2.4.15).

Table 3.2.4.13

| Value of numerical factor $\mu$ |                                                                                     |                  |
|---------------------------------|-------------------------------------------------------------------------------------|------------------|
| Nos.                            | Type of load and fastening of framing member support sections                       | $\mu \cdot 10^2$ |
| 1                               |    | 3,125            |
| 2                               |   | 7,688            |
| 3                               |  | 10,417           |
| 4                               |  | 4,167            |
| 5                               |  | 3,646            |
| 6                               |  | 8,333            |

**3.2.4.16** A passage assembly of longitudinals with the section core depth  $H_c^{prim}$  through transverses with the section core depth  $H_c^{tran}$  is prepared by matting on angle straps so that  $H_c^{prim} < 0,7H_c^{tran}$ .

The core of the transverse framing member during its installation is connected to longitudinal webs and face plate by means of compound or paste based on chopped fibers

and binder, while transverse webs shall be thickened by 30 – 40 % by adding fabric layers to compensate for an opening passing the longitudinal (refer to Fig. 3.2.4.16).

**3.2.4.17** Longitudinals (stringers, deck girders) shall terminate either behind the bulkhead while decreasing gradually in depth (refer to Fig. 3.2.4.17, a), or on the bulkhead connecting to it by means of moulding-in angles and a closed box section bracket (refer to Fig. 3.2.4.17, b). In the latter case the bracket core shall be manufactured from the same foam plastic as the framing member core and connected to the framing member face plate and bulkhead with adhesive or paste.

**3.2.4.18** Transverse members (floors, frames and beams) shall be aligned.

Depending on the depth of longitudinals and transverses, the latter may pass through longitudinals with a passage assembly in accordance with Fig. 3.2.4.16.

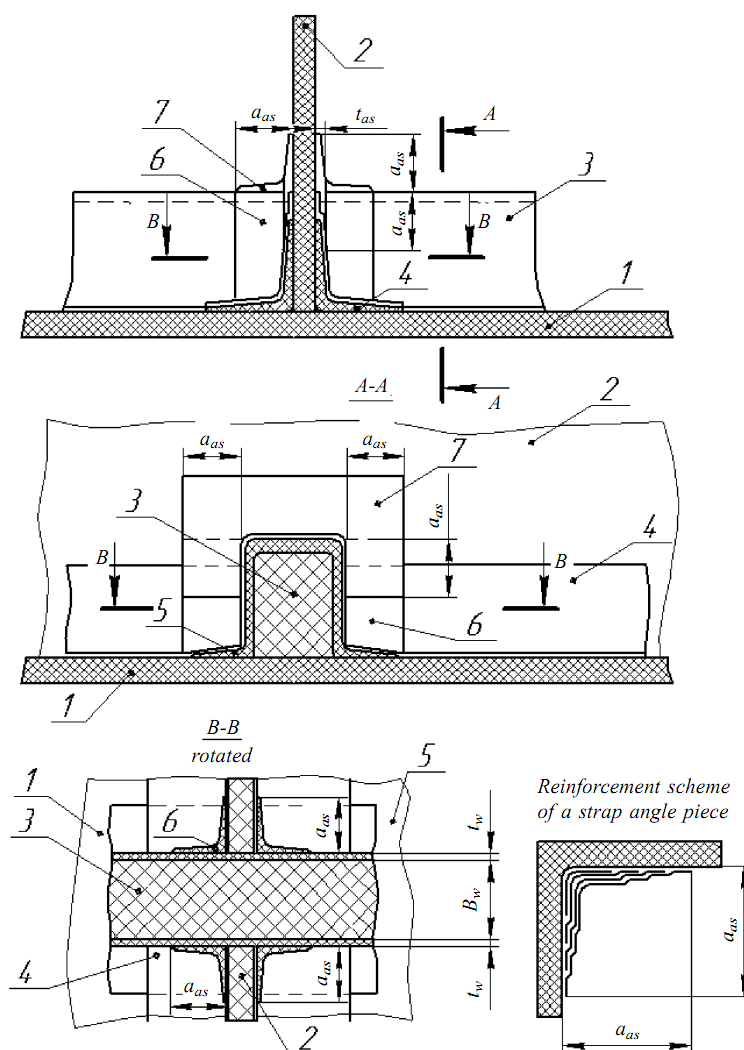


Fig. 3.2.4.15

Passage assembly for a closed box section framing member running through the watertight transverse bulkhead:

1 – shell (deck plating); 2 – bulkhead; 3 – framing member; 4 – bulkhead moulding-in angles; 5 – framing member flanges; 6 – angle straps connecting framing member webs to the bulkhead; 7 – angle strap connecting its face plate to the bulkhead: ( $t_{as} \cong (0,5 - 0,7)t_w$ ,  $a_{as} \cong 10t_{as}$ )

Where the passage assembly cannot be carried out in accordance with Fig. 3.2.4.16 (values of framing member depths are the same or approximately the same) shall be intercostal provided that longitudinals are continuous. In this case, a reliable connection shall

be provided between framing member elements at their intersections, by means of adhesives and matted-on sheathings ([refer to Fig. 3.2.4.18](#)).

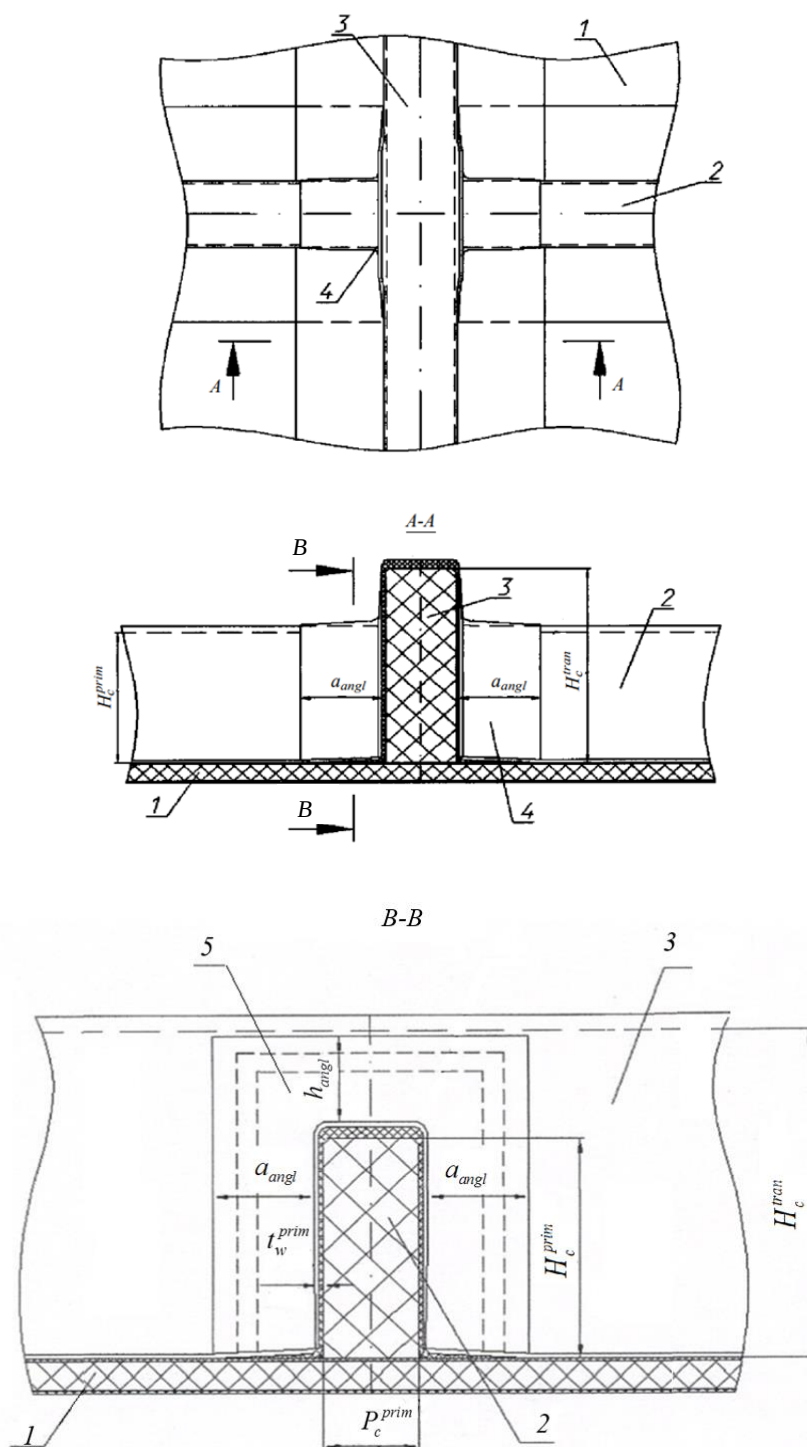


Fig. 3.2.4.16

Intersection of closed box sections of different depths:

1 – shell (deck); 2 – longitudinal; 3 – transverse; 4 – angle straps; 5 – thickening of transverse webs:

$$a_{angl} \geq B_c^{prim}; t_{angl} = 0,8 t_w^{prim}; h_{angl} \cong (H_c^{tran} - H_c^{prim}) \leq a_{angl}$$

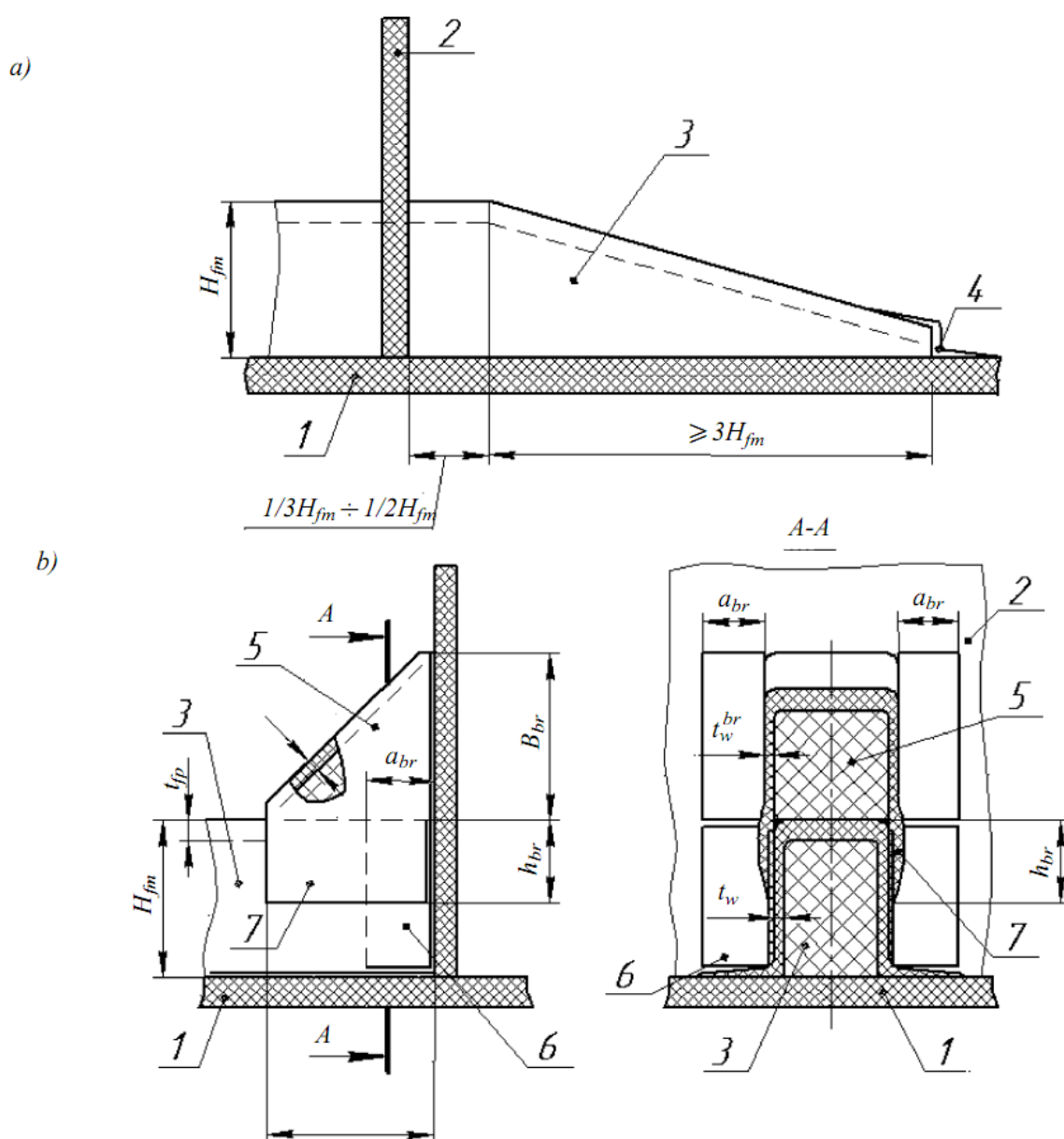


Fig. 3.2.4.17

Terminations of closed box section longitudinals:

 a) – bevel behind the bulkhead (design of the framing member passage through the bulkhead – [refer to Fig. 3.2.4.16](#));

b) – on the bulkhead with a closed box section bracket installed;

1 – shell (plating); 2 – bulkhead; 3 – framing member; 4 – moulding of the framing member end; 5 – bracket;

 6 – angle strap connecting framing member webs to the bulkhead; 7 – bracket sheathing continued on framing member webs:  $B_{br} \cong H_{fm}$ ,  $t_{fp}^{br} \geq 0,8t_{fp}$ ,  $t_w^{br} \cong t_w$ ,  $t_{angl} \cong t_w$ ,  $a_{br} \geq 12t_w$ ,  $1/2H_{fm}) > h_{br} \geq 10t_w^{br}$ 

**3.2.4.19** Where the transverse frame member (frame) terminates on the longitudinal (stringer, deck girder), attachment of the first member end shall be ensured.

The intersection shall be performed by connecting the transverse frame core to longitudinal webs by means of adhesive, followed by moulding-in angles and the strap ([refer to Fig. 3.2.4.19](#)).

**3.2.4.20** Reinforced floor and beam shall be in line with the web frame to form a ring structure.

Web frame scantlings shall be selected so that the value of its bending stiffness shall be at least 4 times that of the main frame.

The depth of reinforced floors shall be equal to at least the depth of the centre girder or side girders, whichever is greater. The depth of the reinforced beam shall be equal to at least 0,8 of the web frame depth.

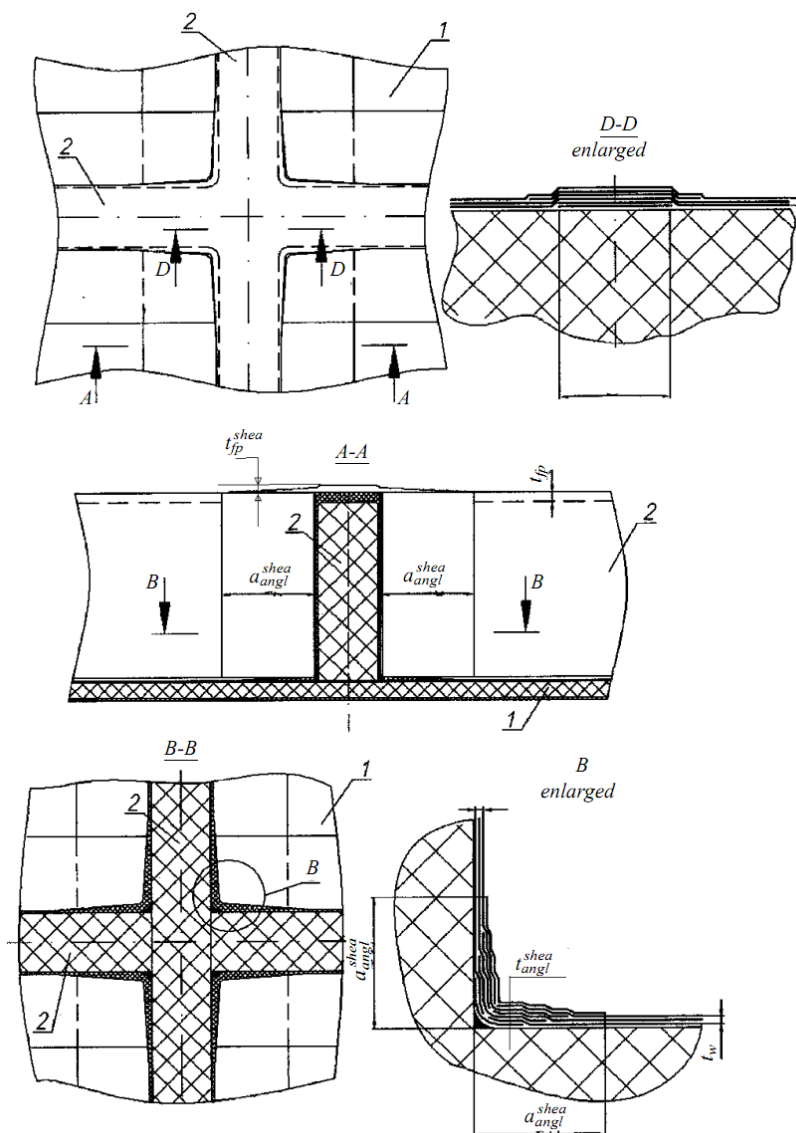


Fig. 3.2.4.18

Intersection of the longitudinal and intercostal transverse framing members of similar depths, with continuous face plates:

1 – shell (deck); 2 – framing members (scantlings of matted-on sheathings shall be determined according to the following formula:  $t_{fp}^{shea} \cong t_{fp}$ ;  $t_{angl}^{shea} \cong t_w$ ;  $a_{angl}^{shea} \geq 12t_{angl}^{shea}$

**3.2.4.21** The web frame is connected to the upper deck beam with a closed box section bracket, which core shall be manufactured from the foam plastic used in framing members being connected. In such case, it is recommended that the deck beam and frame section widths shall be equal to each other where a bracket is fitted, while the width of one framing member (beam, in general) gradually increases to the width of another member (frame).

The bracket core sheathing overlaps member webs, with its thickness gradually decreasing. The bracket face plate shall be thickened as compared to the webs by adding reinforcing fabric layers ([refer to Fig. 3.2.4.21](#)).

**3.2.4.22** The frame shall be continuous through the intermediate deck (platform) laminates. If necessary, its section depth may decrease gradually when passing through the deck laminates from the bottom tier to the upper one. The frame is connected to the intermediate deck (platform) beam with a bracket, which geometric parameters shall be selected in accordance with [Fig. 3.2.4.22](#).

For the frame to pass through the deck laminate, an opening in the laminate shall exceed the frame section depth and width by 4 – 5 mm.

**3.2.4.23** Vertical stiffeners of transverse bulkheads shall be in line with stringers and deck girder and continuous through intermediate decks (platforms).

They shall be connected to longitudinals (stringers, deck girders) by means of a closed box section bracket consisting of a core made of the same foam plastic as in the stiffener and in the sheathing ([refer to Fig. 3.2.4.23](#)).

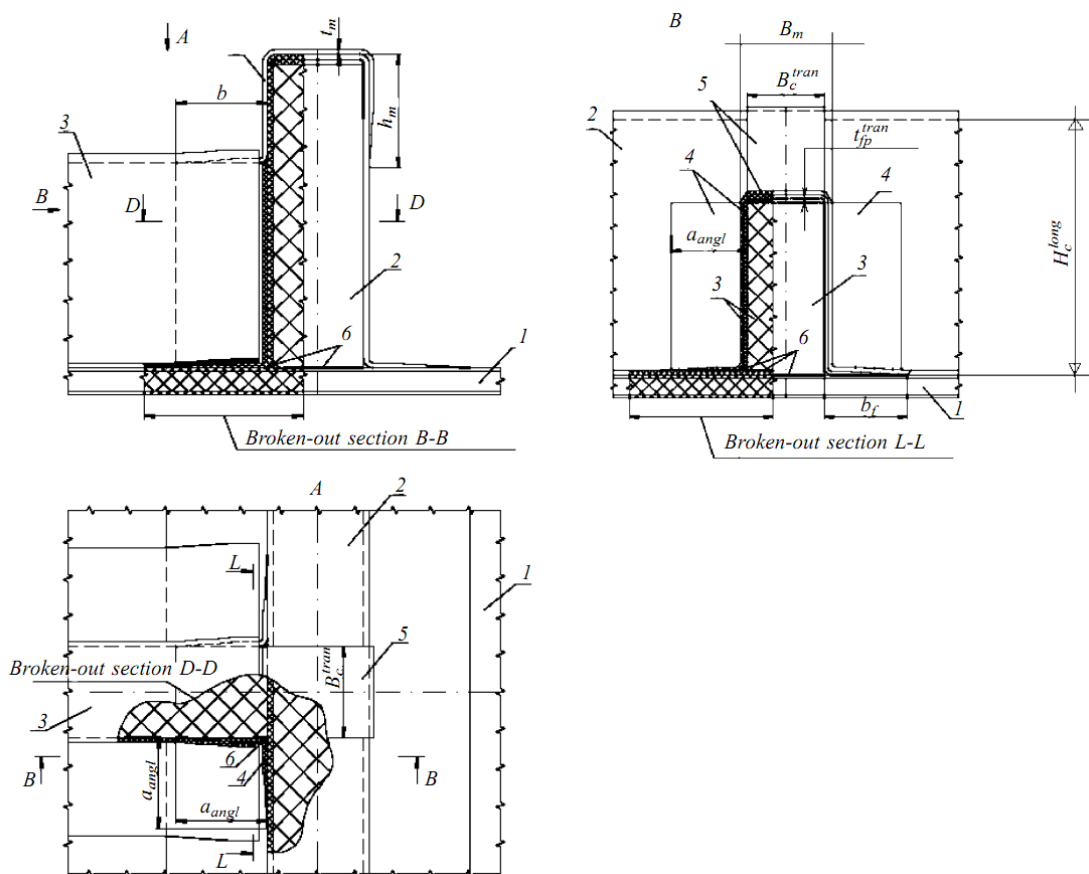


Fig. 3.2.4.19

Termination and joint of the transverse to the longitudinal:

1 – shell (plating); 2 – longitudinal; 3 – transverse; 4 – moulding-in angles; 5 – strap; 6 – glue

$$t_{angl} \cong t_w^{tran}; a_{angl} \geq 12t_w^{tran}; B_m = B_c^{tran} + 2t_w^{tran}; t_m \geq 0,8t_{fp}^{tran}; \frac{1}{(2H_c^{long})} > h_m \geq 10t_m$$

**3.2.4.24** Brackets in connections of framing members may be made as an individual closed box section element, which is then mounted on face plates of connected members by means of adhesive or paste, and straps are matted on webs of the bracket and members ([refer to Fig. 3.2.4.24](#)).

**3.2.4.25** Intermediate stiffeners that are fitted to stiffen the bulkhead plating between main stiffeners may be sniped at their ends (near the bottom and upper deck) ([refer to Fig. 3.2.4.25](#)). Intermediate stiffeners may be cut on intermediate decks and platforms.

Main stiffeners may be sniped based on the strength calculations and the RS approval.

**3.2.4.26** Scantlings of closed box section stiffeners shall be determined according to the requirements of [3.2.4.7](#) and confirmed by the results of buckling strength calculations ([refer to Appendix 1](#)).

**3.2.4.27** All connecting elements in connections of framing members to each other and to other hull members shall have a parallel reinforcement scheme and based on woven roving and biaxial fabrics with reinforcement ( $0^\circ/90^\circ$ ).

Sheathings of brackets shall be of parallel and diagonal reinforcement scheme with the use of quadriaxial fabrics with reinforcement ( $0^\circ/+45^\circ/90^\circ/-45^\circ$ ), or a mix of fabrics with reinforcement ( $0^\circ/90^\circ$ ) and ( $+45^\circ/-45^\circ$ ).

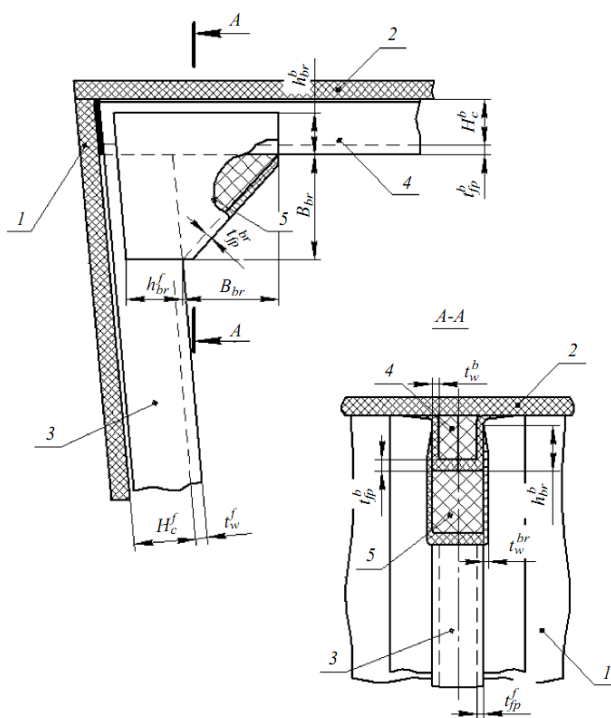


Fig. 3.2.4.21

Joint of the frame and upper beams:

1 – side plating; 2 – upper deck plating; 3 – frame; 4 – beam; 5 – bracket  
 $B_{br} \geq 0,8(H_c^b + H_c^f); t_{fp}^{br} = 1/2(t_{fp}^b + t_{fp}^f); t_w^{br} = 1/2(t_w^b + t_w^f); h_{br}^{b(f)} = 0,8H_c^{b(f)}$

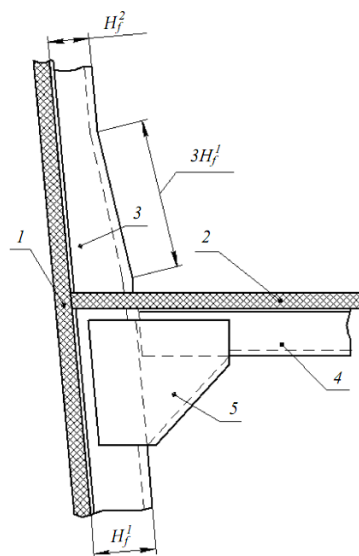


Fig. 3.2.4.22

Joint of the frame and intermediate deck (platform) beam:

1 – side plating; 2 – intermediate deck (platform) plating; 3 – frame; 4 – beam; 5 – bracket

**3.2.4.28** Openings in face plates of framing members are not allowed.

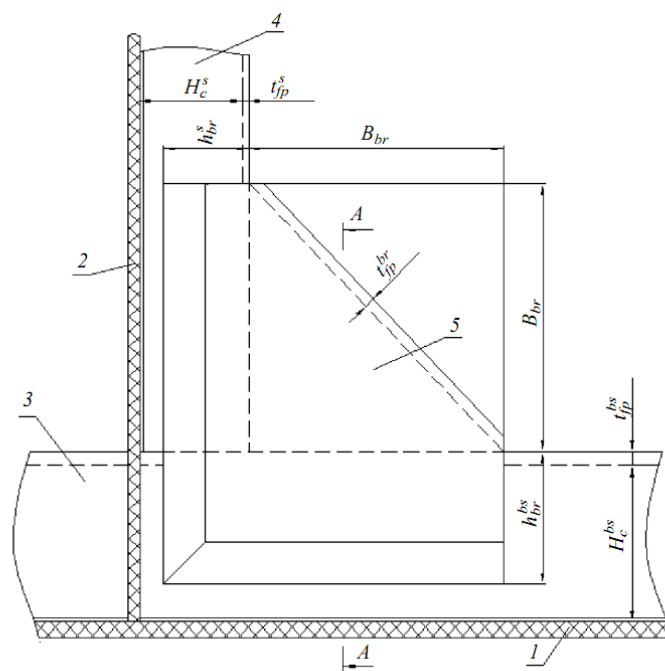
Openings in the framing member webs for the passage of passing pipes, cables, etc., are allowed with a maximum linear dimension not exceeding  $1/3$  of the member section (core) depth. Webs shall have parallel and diagonal reinforcement scheme  $[(0^\circ/+45^\circ/90^\circ/-45^\circ)]$ .

Openings with diameter less than  $1/5$  of the member section depth are allowed not to be reinforced. Openings with diameter more than  $1/3$  of the member section depth shall be reinforced. Reinforcement shall be performed by matting-on a strap along the section perimeter, with member webs and a face plate ([refer to Fig. 3.2.4.28](#)).

Strap material shall correspond to that of the framing member sheathing where an opening is located. Parallel and diagonal reinforcement scheme of the strap  $[(0^\circ/+45^\circ/90^\circ/-45^\circ)]$  shall be used.

**3.2.4.29** The framing members shall be provided with water courses (scuppers to drain water and other liquids).

Openings for scuppers in framing webs of closed box sections shall be reinforced by placing a thin-walled former manufactured of fiber-reinforced plastic using paste. Scupper opening depth shall be equal to 5 – 50 mm ([refer to Fig. 3.2.4.28](#)).



A-A

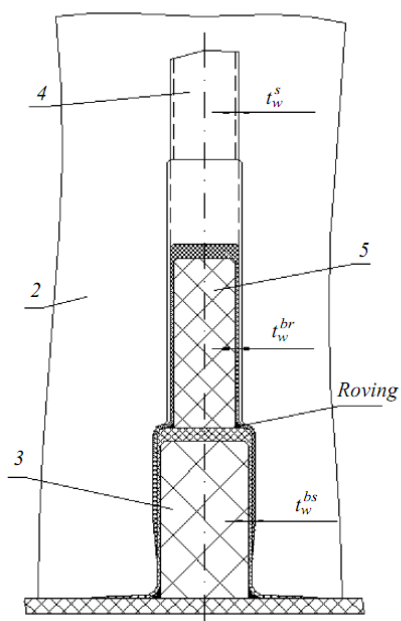


Fig. 3.2.4.23

Joint of the bulkhead stiffener and longitudinal (stringer, deck girder):

1 – bottom plating (deck plating); 2 – bulkhead plating; 3 – longitudinal bulkhead; 4 – stiffener; 5 – bracket

$$B_{br} \geq 1,5H_c^s; t_{fp}^{br} = 1/2(t_{fp}^s + t_{fp}^{bs}); t_w^{br} = 1/2(t_w^s + t_w^{bs}); h_{br}^{bs(s)} = 0,7H_c^{bs(s)}$$

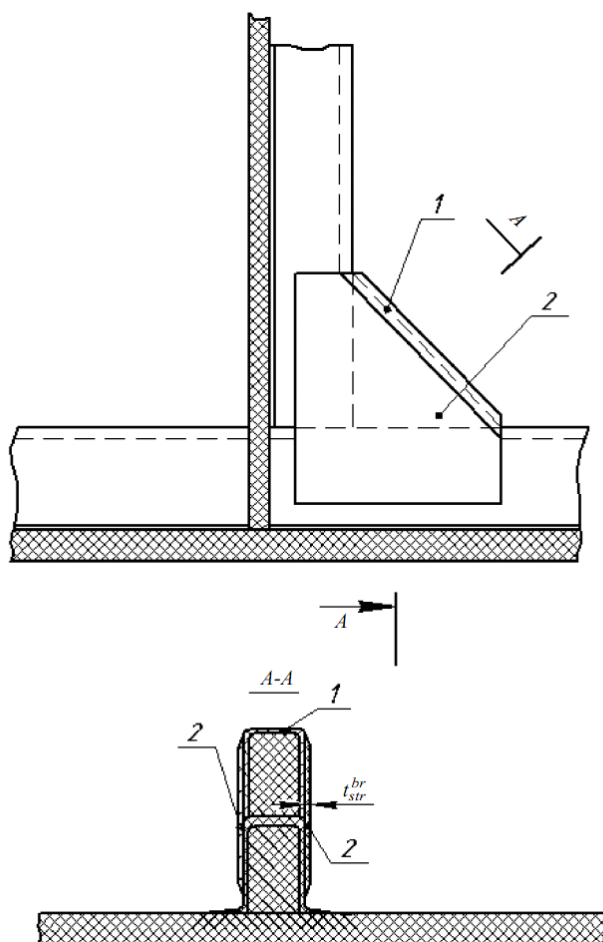


Fig. 3.2.4.24  
Joint of the bracket and framing members by means of straps:  
1 – bracket; 2 – straps ( $t_{str}^{br} \approx t_w^{br}$ )

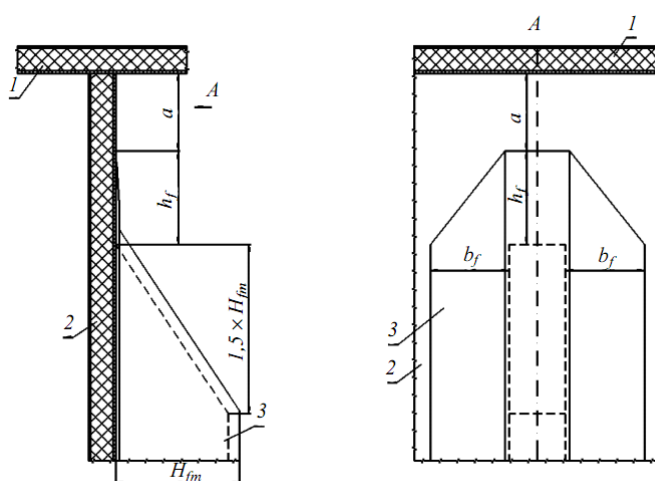


Fig. 3.2.4.25  
Beveled termination of the bulkhead stiffener:  
1 – bottom plating (deck plating); 2 – bulkhead plating; 3 – closed box section member

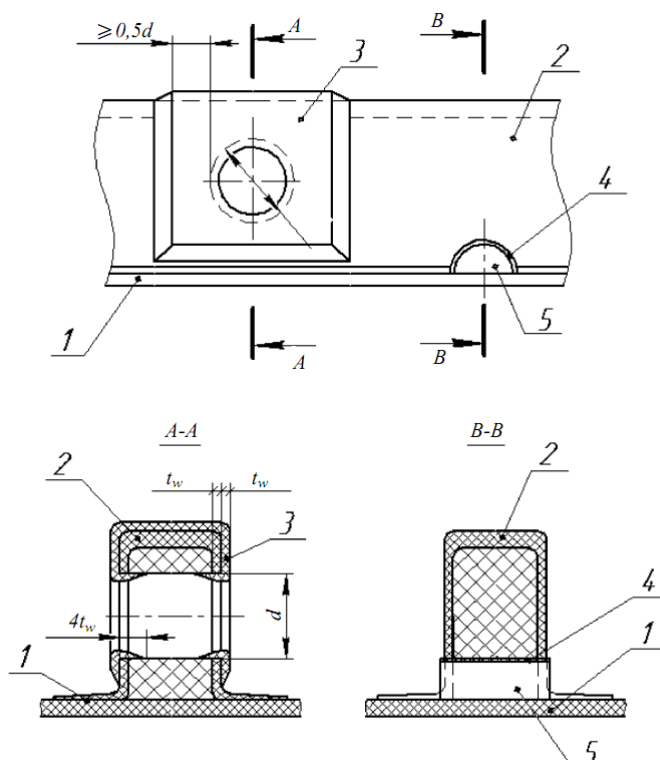


Fig. 3.2.4.28

Reinforcement of openings in closed box sections of the framing members

1 – shell plating (deck plating, platform); 2 – member; 3 – strap; 4 – opening former; 5 – water course (scupper)

### 3.2.5 Openings.

**3.2.5.1** All openings in the side, deck, and bulkhead platings shall be reinforced where their minimum linear dimension exceeds the following values (whichever is less):

15 thicknesses for single-skin structures, or 150 mm;

5 thicknesses for sandwich structures, or 250 mm.

**3.2.5.2** Openings in single-skin structures are reinforced by local thickening of the shell (deck laminate, plating) around the opening on the area with dimensions determined in accordance with Fig. [3.2.5.2-1](#), a and [3.2.5.2-2](#).

It is allowed to increase thickness by means of straps where infusion technique is applied for the structure manufacture, or where an opening location has not been determined earlier and its minimum dimension does not exceed 30 thicknesses of the shell (deck laminate, plating). Otherwise, the thickness shall be increased in advance by moulding additional fabric layers between basic ones.

**3.2.5.3** To reinforce openings in the shell, deck and bulkhead plating of the sandwich structure, the following techniques are recommended to be applied:

local thickening of load-bearing layers over the specified area around the opening;

replacement with a foam plastic with higher density over the thickness at least  $3h$  where  $h$  is 1/2 of the core thickness from the edge of a foam plastic opening, along the opening contour (refer to Fig. [3.2.5.2-1](#), b and [3.2.5.3](#)).

Load-bearing layers shall be thickened with straps by matting on additional fiber layers simultaneously with moulding of the structure edge along the opening contour.

Density of the foam plastic added in the core along the opening contour shall be 30 — 40 kg/m<sup>3</sup> higher than that of the entire core in the structure, but not more than 200 kg/m<sup>3</sup>. In this case, where the core is made of the lightweight mat reinforced with fabric (refer to Fig. 3.1.1, c), its reinforcement along the opening contour is not required.

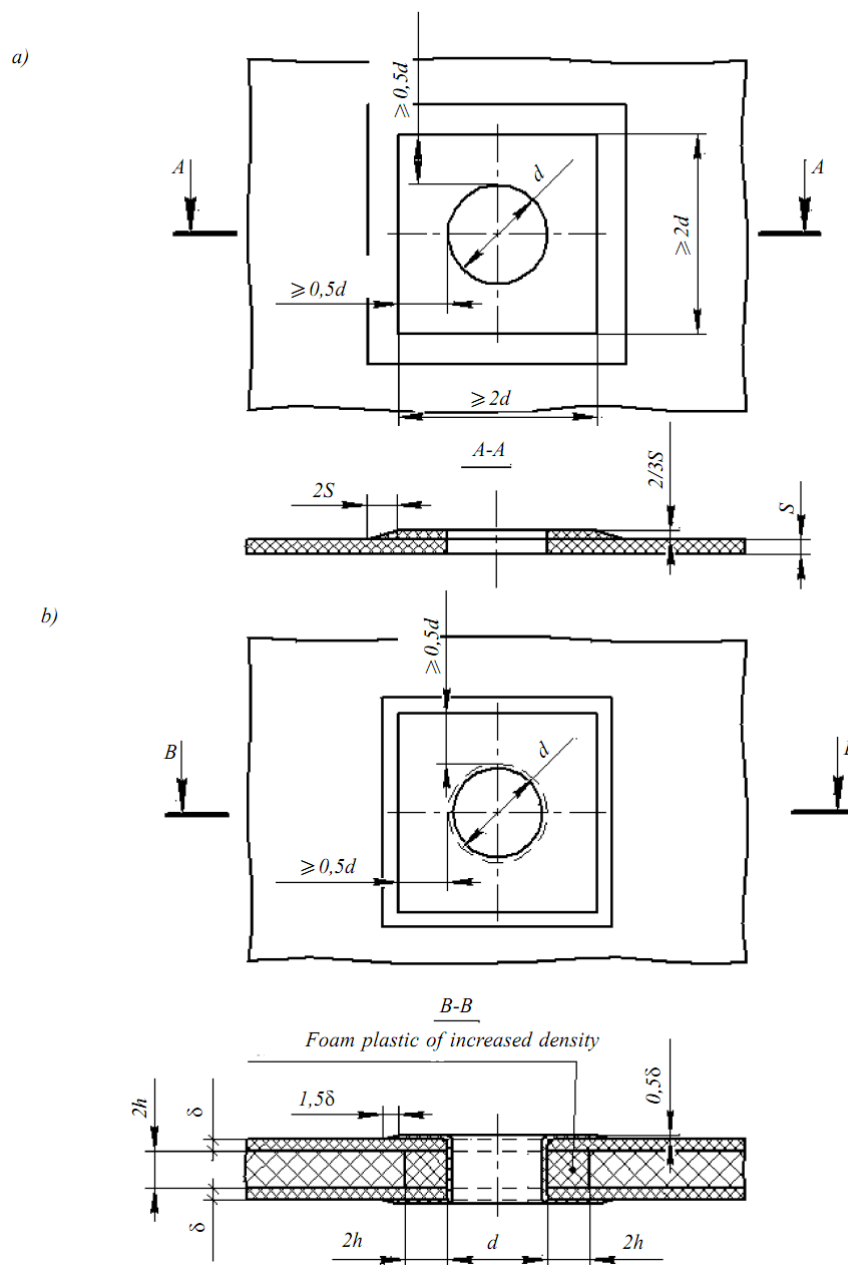


Fig. 3.2.5.2-1  
Reinforcement of a round opening in single-skin (a) and sandwich (b) structures

**3.2.5.4** The structure around the opening shall be thickened using the same fabrics as for the structure manufacture.

Round openings may be reinforced with woven roving and biaxial fabrics with reinforcement (0°/90°), (+45°/−45°) or with a combination thereof.

The reinforcement scheme of the thickened area around a rectangular opening shall, as far as possible, be the same as where this opening is located.

Thickening tapering shall be gradual, with each fabric layer overlapped over 30 — 50 mm with the subsequent layer.

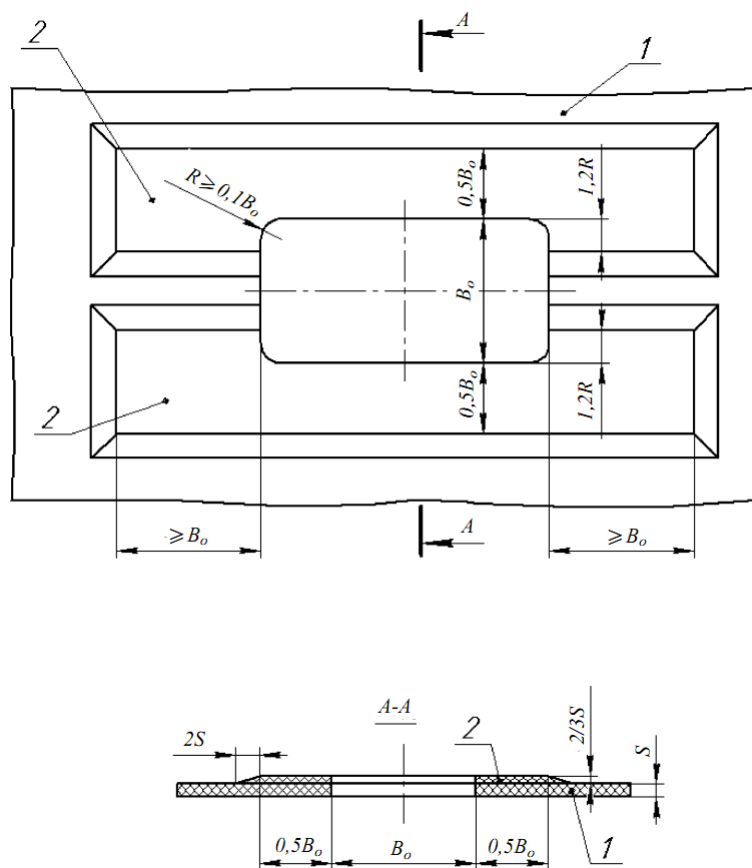


Fig. 3.2.5.2-2

Reinforcement of a rectangular opening in a single-skin structure:  
1 – deck (platform) plating; 2 – thickening

**3.2.5.5** Comparatively large openings in the deck, which width exceeding  $1/4 - 1/3$  of the deck width, shall be reinforced with coamings.

Coamings may be manufactured from the same materials as the deck and have either closed box or L-shaped cross section. They may be also made of metal, e.g. standard coamings of hatchway covers.

Openings may not be provided with coamings. In this case, they shall be confined with deck girders and beams that shall be placed as close as possible to the opening edge, equal to the framing member flange width. Where this is not possible, additional members shall be provided, their terminations considering the provisions of [3.2.4.17](#).

**3.2.5.6** In exceptional cases, two or more deck openings spaced from each other to a distance measured between their edges and equal to less than 1,5 of the smallest opening width are allowed. Such openings shall be reinforced by increasing the plating thickness on the entire deck area where such group of openings is located.

Where the deck has a sandwich structure with the foam plastic in a core, in addition to thickening of load-bearing layers, the foam plastic of increased density shall be added along opening contours, according to the provisions of [3.2.5.3](#).

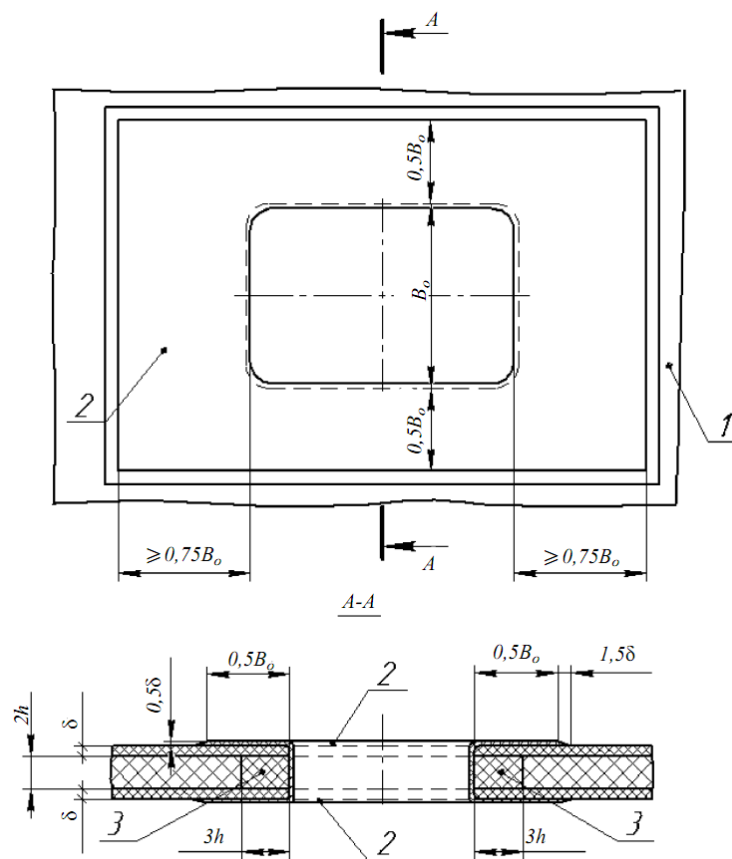


Fig. 3.2.5.3

Reinforcement of a rectangular opening in a sandwich structure:

1 – deck (platform) plating; 2 – thickening of load-bearing layers; 3 – foam plastic of increased density

**3.2.5.7** Where the distance between openings is longer than that specified in [3.2.5.6](#), a decision to increase the thickness of the laminate or load-bearing layers on the entire deck area where openings are located, or around each opening individually, or around separate openings, shall be taken on the basis of structural particulars and approved by the Register.

**3.2.5.8** Openings around a deck stringer are not allowed. In exceptional cases, round holes of not more than 150 mm in diameter are allowed in a deck stringer. Opening edges shall be reinforced according to [3.2.5.2](#) and [3.2.5.3](#).

### 3.2.6 Joints.

#### 3.2.6.1 General.

**.1** these requirements are applied to moulded butt (seam) and fillet joints of hull structural members, which are made with the use of adhesives and butt straps moulded layer by layer and moulding-in angles;

**.2** butt straps and moulding-in angles shall be made of the same materials and have the same reinforcement scheme as the members being jointed;

**.3** butt and angle joints between contact surfaces of the members being jointed shall be provided with adhesives, the properties of which shall ensure the specified strength of the joint and enable using it under production conditions of the shipyard, considering the requirements of [2.3.4](#);

**.4** butt straps and moulding-in angles shall be moulded by either infusion or contact moulding techniques while complying with the requirements for quality of preparation of surfaces being jointed and relative content of binder during moulding of straps and angles in accordance with the process regulations;

**.5** selected parameters of joints, considering the requirements of [3.2.6.2](#) and [3.2.6.3](#), shall be specified based on the results of strength calculations.

### 3.2.6.2 Moulded butt joints.

**.1** material and reinforcement scheme of straps in moulded butt joints shall match the members being jointed ([refer to 3.2.6.1.2](#)). Fabrics with reinforcement ( $0^\circ/90^\circ$ ) may be laid with  $0^\circ$  direction along the butt, however in this case the breaking load in  $90^\circ$  direction shall not be lower than that in  $0^\circ$  direction;

**.2** where the thickness of single-skin members being jointed does not exceed 10 mm, edge preparation may be omitted ([refer to Fig. 3.2.6.2.2](#)).

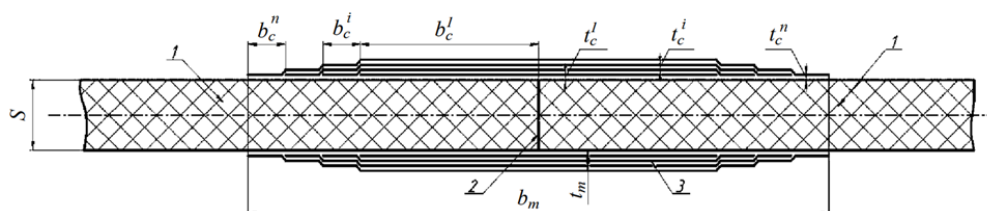


Fig. 3.2.6.2.2

Structural scheme of a moulded butt (seam) joint of single-skin members without edge preparation:

1 – members being jointed; 2 – butt; 3 – straps

For this type of joint, strap parameters shall be selected from the following:

$b_m \geq 180 + 15s$ , in mm;

$b_c^1 = 30 \div 50$ , in mm — half width of the first fiber layer of the strap;

$b_c^i = 15 \div 25$ , in mm — step width;

$b_c^n = 40 \div 50$ , in mm — width of the last  $n$ -th step of the strap;

$t_m \geq 0,5s$ , in mm — for butt straps with parallel reinforcement scheme ( $0^\circ/90^\circ$ );

$t_m \geq 0,8s$ , in mm — for butt straps with parallel and diagonal reinforcement scheme ( $0^\circ/90^\circ$ )( $+45^\circ/-45^\circ$ );

$t_c^1, t_c^i, t_c^n$  — step height equal to the total thickness of the fiber layers forming the step;

**.3** where the thickness of single-skin members exceeds 10 mm, butt joints shall be made with stepped edge preparation and beveling. These types of joints shall be used for connection of sandwich members;

**.4** butt joint with stepped edge preparation is made by sequential removal of reinforcing material layers in members being connected around the butt ([refer to Fig. 3.2.6.2.4](#)).

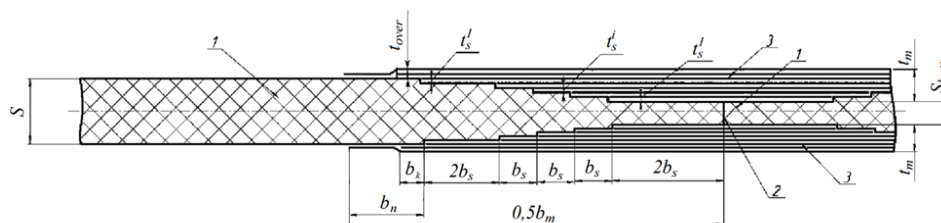


Fig. 3.2.6.2.4

Structural scheme of a moulded butt (seam) joint of single-skin members with double side stepped edge preparation:

1 – members being jointed; 2 – butt; 3 – straps

Joint parameters for single-skin members shall be selected from the following:

$s'_{butt} = 0,25 s \geq 2$ , in mm;

$m_1 = s'_{butt}/t_d$  (where  $m_1$  is a fractional number, it is rounded to the smallest integral value);

$n_1 = (m - m_1)/2$ ;

where  $n_1$  is a fractional number, then  $m_{butt} = m_1$ ;

where  $n_1$  is a fractional number, then  $m_{butt} = m_1 + 1$ , whereas  $n_1$  is rounded to the smallest integral value);

$s_{butt} = t_d m_{butt} \geq 2$ , in mm;

$n_2 = (n_1 - 6)/3$  (where  $n_2$  is a fractional number, it is rounded to the smallest integral value);

$n = 4 + n_2 + k$ ;  $b_d \geq 2[(n + 2) \cdot b_s + b_n]$ , in mm;

$b_n = 2b_s \geq 40$ , in mm; at  $b_s = 20 \div 30$ , in mm;

$b_k = b_s$ ;

$s_{butt}$  = end butt thickness,

$t_m > 0,5(s - s_{butt}) + t_{over}$ , in mm

where  $n$  = number of preparation steps;

$m$  = number of fiber layers in a panel;

$m_{butt}$  = number of fiber layers in the butt of panels  $s_{butt}$ ;

$s'_{butt}$  = initial butt thickness;

$s_{butt}$  = end butt thickness;

$m_1$  = number of fiber layers in the butt of panels of  $s'_{butt}$  in thickness;

$t_d$  = thickness of one fabric or packet layer;

$t_m$  = strap thickness;

$k$  = factor equal to 0, if  $n_2$  is an integral value, and equal to 1, if  $n_2$  is a fractional number;

Steps shall be of the following depths  $t_c^i$ :

the first  $t_s^1$  and the last step  $t_s^n - 1$  fiber layer;

the second step  $t_s^2 - 2$  fiber layers;

the third  $t_s^3$  and subsequent steps – 2 – 3 fiber layers, the following shall be taken into account:

where  $n_2$  is an integral value, all the steps from the third one to the last but one shall have the thickness equal to 3 fabric layers;

where  $n_2$  is a fractional number, and a figure after the decimal point is equal to 3, then  $(n_2 - 1)$  step shall have the thickness equal to 3 fabric layers and 2 steps with the thickness equal to 2 fabric layers;

where  $n_2$  is a fractional number, and a figure after the decimal point is equal to 6, then  $n_2$  steps shall have the thickness equal to 3 fabric layers and 1 step with the thickness equal to 2 fabric layers;

the last but one step  $t_s^{(n-1)} - 2$  fiber layers.

For other symbols, refer to [Fig. 3.2.6.2.4](#).

The number of external straps with thicknesses  $t_{over} \approx t_d$  is equal to 2.

Butt joint parameters of sandwich members are determined from the following correlations:

$S_{butt} = m'''_{butt} \cdot t_d$ , in mm;

$m'''_{butt} \geq 2$ ;

$n_1 = m''' - m'''_{butt}$ ;

$m'''$  = number of fabric layers in load-bearing layer;

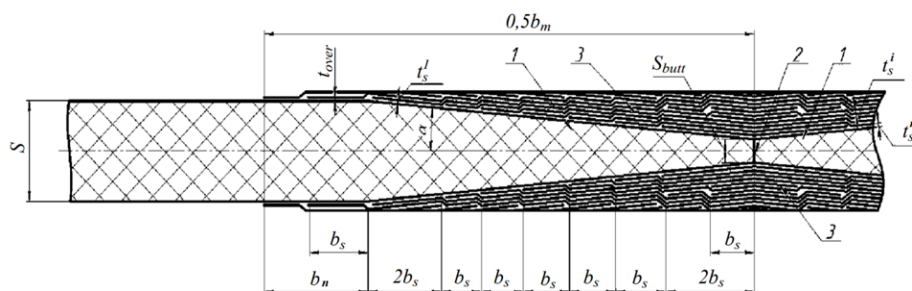
$m'''_{butt}$  = number of fabric layers in the butt of load-bearing layer;

$n_2 = (n_1 - 6)/3$  (where  $n_2$  is a fractional number, it is rounded to the smallest integral value);

$t_m > \delta_{imax}$ , in mm,

$$S_{butt} = \text{thickness of load-bearing layers in the butt.}$$

**.5** structural scheme of the butt joint with beveling for single-skin members is specified in [Fig. 3.2.6.2.5](#).



Structural scheme of a moulded butt (seam) joint of single-skin members with double stepped beveling:  
1 – members being connected; 2 – butt; 3 – straps

$$\alpha \leq 4^\circ;$$

$$\alpha \leq 4^\circ;$$

$$s'_{butt} = 0,125s \geq 2, \text{ in mm};$$

$n = ((s - s_{butt}) / (2\alpha b_s)) - 2$  (where  $n$  is a fractional number, it is rounded to the smallest integral value);

$$b_{\varsigma} = 15 \div 20, \text{ mm}; b_{\eta} = 2b_{\varsigma} \geq 30, \text{ mm};$$

$$\cos \alpha / n(0,6(s - s_{butt}) + 0,2t_{over}n_{over}) \geq t'_n \geq n_1/nt_d \cdot \cos \alpha, \text{ in mm (angle } \alpha, \text{ in deg.)}$$

where  $t'_n$  = strap thickness in butt area.

Other joint parameters are determined from formulas for the stepped joint of single-skin members (refer to 3.2.6.2.4).

Parameters of butt joint with beveling for sandwich members are determined according to the formulae for single-skin member parameters and according to the following formulae:

$\alpha \leq 2^\circ$ ;  $s_{butt}$  = thickness of 1 fabric layer;

$n = (\delta_{imax} - s_{butt})/(\alpha \cdot b_c) - 2$  (where  $n$  is a fractional number, it is rounded to the smallest integral value);

$$\cos \alpha / n \cdot (1, 2(\delta_{imax} - s_{butt}) + 0, 2t_{over}n_{over}) \geq t'_n \geq (\delta_{imax} - s_{butt}) / n \cdot \cos \alpha, \text{ in mm (angle } \alpha, \text{ in deg.)};$$

**.6** to connect members of hull structures, it is allowed to use joints of non-symmetrical thickness with and without edge preparation, e.g. to ensure a smooth outer surface of the deck (platform), beveling is performed on this surface, whereas on the opposite surface a strap is matted on the butt without edge preparation.

Straps with and without edge preparation shall be selected considering the requirements of 3.2.6.2.2, 3.2.6.2.4 and 3.2.6.2.5;

.7 application of other butt (seam) joints for single and sandwich members of hull structures shall be substantiated based on the calculation and experimental results and agreed with the Register.

### 3.2.6.3 Moulded fillet joints.

**.1** in moulded fillet joint that are not subject to significant shear in member reinforcement planes, the reinforcement scheme of moulding-in angles shall be  $[(0^\circ/90^\circ)]$ , with  $0^\circ$  direction along the joint. In this case, the breaking load in  $90^\circ$  direction shall be not lower than that in  $0^\circ$  direction.

Where the members being jointed are exposed to higher shear strains, the reinforcement scheme of moulding-in angle shall be parallel and diagonal  $[(0^\circ/+45^\circ/90^\circ/-45^\circ)]$ , for which purpose it is recommended to use combination of two fabrics  $(0^\circ/90^\circ)$  and  $(+45^\circ/-45^\circ)$ , each of not more than 0,5 mm in thickness, to ensure their fitting to connection angles;

.2 when moulding-in angles in fillet joints, their thickness shall taper from the root towards leg terminations by each next fabric layer overlapping the preceding one over value  $a_{angl}$ , which is assumed equal to  $a_{angl} = 10 - 15$  mm (refer to [Fig. 3.2.6.3.2](#));

Basic parameters of moulding-in angles in single-skin member joint shall be selected from the following:

$$t_{angl} \geq 0,8s, b_{angl} \geq 15t_{angl} \text{ or } b_{angl} \geq 100 + 5s \text{ (whichever is greater)}$$

where  $s$  = thickness of a horizontal member, in mm;

$$R_{angl} \geq 1,5t_{angl};$$

.3 contact surface of vertical and horizontal members and angles, shall be coated with adhesion that serves for joint of members and rounding of angles prior to moulding of moulding-in angles ([refer to Fig. 3.2.6.3.2](#));

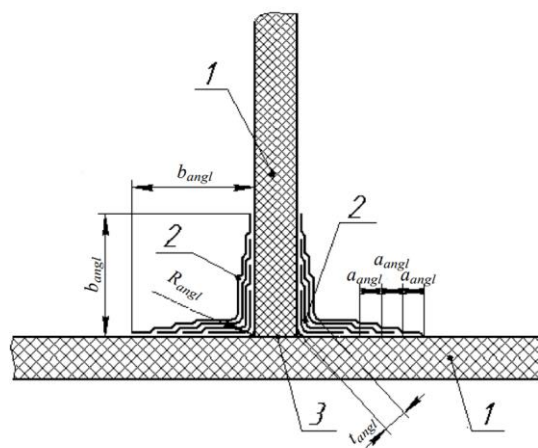


Fig. 3.2.6.3.2

Structural scheme of a moulded fillet joint:

1 – members being jointed; 2 – moulding-in angles; 3 – contact surface

.4 for a stressed fillet joint, a horizontal single-skin member may be thickened under a vertical member, which may be both single-skin and sandwich, e.g. joint of a single-skin hull shell with a sandwich bulkhead. The foam plastic in core of the bulkhead in the area of joint with single-skin shell shall be replaced by that of the density increased by  $30 \div 40 \text{ kg/m}^3$  (but not more than  $200 \text{ kg/m}^3$ ) in the form of embedded elements of certain scantlings ([refer to Fig. 3.2.6.3.4](#)).

The shell is thickened by adding fiber layers (woven roving or biaxial fabric with  $(0^\circ/90^\circ)$  reinforcement) between basic layers along the vertical member (across the hull). Thickness of the thickened area shall taper towards edges, with each next fabric layer overlapping the preceding one with 20 — 25 mm increment. Thickened area scantlings shall be determined from the following:

$$t_{th} = (0,2 \div 0,3)S_{shell};$$

$$B_{th} \geq 2(b_{th} + 6t_{th}) + S_{bulk}, b_{th} = b_{angl} + 5 \text{ mm};$$

$$b_{angl} \geq 16t_{angl}, t_{angl} \geq 0,6s_p,$$

where  $s_p = \max(S_{shell}, S_{bulk})$  — for connection of single-skin members;

$S_p = \max(S_{shell}, \delta_{bulk} + \delta_{bulk})$  — for connection of a single-skin and a sandwich members;

$\delta_{bulk}$  = thickness of the load-bearing layer of sandwich member;

$$R_{angl} = 2t_{angl};$$

$$l_{angl}^{bulk} = 1,2 S_{bulk};$$

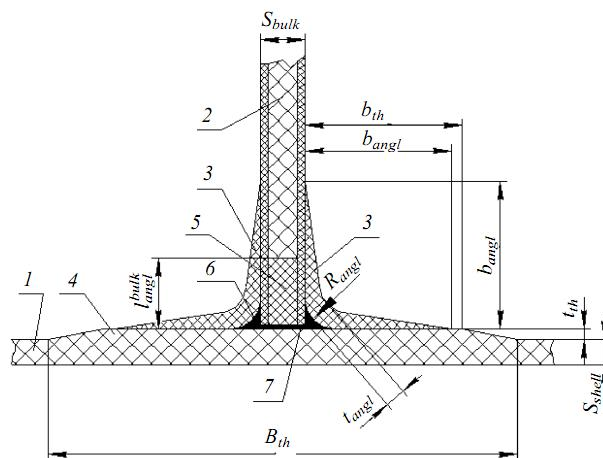


Fig. 3.2.6.3.4

Joint of a sandwich bulkhead with a single-skin hull shell with reinforcement under the bulkhead:

1 – shell; 2 – bulkhead; 3 – moulding-in angles; 4 – thickening; 5 – foam plastic of increased density; 6, 7 – adhesive

.5 where both members, e.g. a bulkhead and a shell, are of sandwich construction and stressed, their fillet joint shall be made with triangular support elements made of foam plastic of  $150 \div 200 \text{ kg/m}^3$  density, which shall be mounted on the shell from both sides of a transverse bulkhead via adhesive which is applied on the contact surface of the bulkhead to shell joint. The edge of a vertical member (bulkhead) shall be sheathed with 2 – 3 layers of woven roving passing over onto outer surfaces to the depth equal to at least the value of its thickness.

The foam plastic in cores of the bulkhead and shell shall be replaced by that of the density increased by  $30 \div 40 \text{ kg/m}^3$  (but not more than  $200 \text{ kg/m}^3$ ) in the form of embedded elements of certain scantlings in the joint area ([refer to Fig. 3.2.6.3.5](#)).

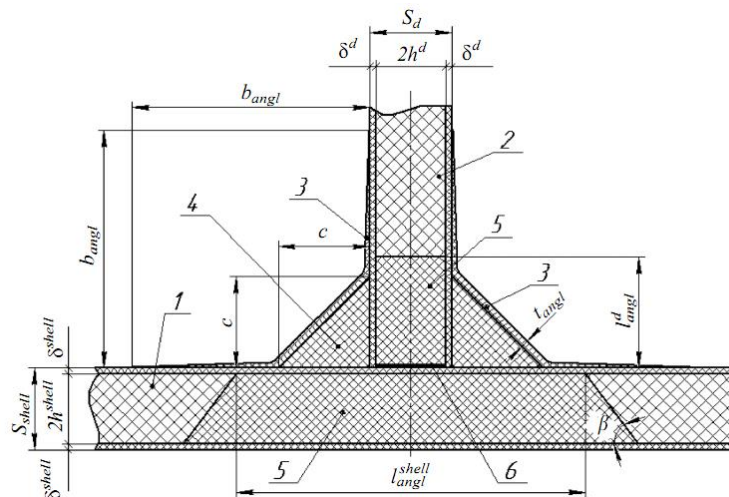


Fig. 3.2.6.3.5

Joint of the hull shell and sandwich bulkhead:

1 – shell; 2 – bulkhead; 3 – matted-in angles; 4 – support elements; 5 – embedded parts; 6 – adhesive

Basic parameters of these joints shall be selected from the following:

$$c \geq 0,6(S_{shell} + S_{bulk}); l_{angl}^d = 0,2s_d; l_{angl}^{shell} = 2(1,1c + S_{shell}) + s_d;$$

$$t_{angl} = 1,2\max(\delta^d, \delta^{shell});$$

$$b_{angl} = 16t_{angl} + c \geq 2S_{shell}; R_{angl} \geq 2t_{angl}; \beta = 45^\circ;$$

**.6** fillet joint of the side and upper deck of single-skin construction may be made by means of matted-in angles provided that the maximum side thickness does not exceed 14 mm.

In this case, the leg size  $b_{angl}$  of moulding-in angles, their thickness at the root  $t_{angl}$  and inner radius  $R_{angl}$  of side to deck transition shall be determined from the following correlations:

$$b_{angl} \geq 100 + 8S_s, t_{angl} \geq 0,8S_s, R_{angl} \geq 2S_s$$

where  $S_s$  = side (sheerstrake) thickness where it connects to the upper deck;

**.7** where single-skin side and deck have comparatively greater thicknesses (over 15 – 20 mm), their angle joint shall be made by thinning the side and deck platings where they connect to each other and by installation of a triangular support element made of the foam plastic of increased density 150 – 200 kg/m<sup>3</sup> ([refer to Fig. 3.2.6.3.7](#)).

Basic parameters of this joint shall be assumed as follows:

$$c \geq 2\max(S_s, S_d);$$

$$h_d \geq 0,5S_d; h_s \geq 0,5S_s;$$

$$t_{angl}^{out} \geq 0,6S_s; b_{angl}^{out} \geq 20t_{angl}^{out};$$

$$t_{angl}^{in} \geq 0,4S_s; b_{angl}^{in} \geq 16t_{angl}^{in} + c;$$

$$l^d = b_{angl}^{out} - s^d; l^s = b_{angl}^{out} - S_s.$$

**.8** where the upper deck and side platings are of sandwich constructions, the following design joint types may be allowed:

Type A. The deck laminate is connected to the side laminate with adhesive and moulding-in angles, with the use of a support element made of the foam plastic of increased density 150 – 200 kg/m<sup>3</sup>. In the place of joint, the upper deck laminate / edge is sheathed with 2 – 3 layers of woven roving with (0°/90°) reinforcement ([refer to Fig. 3.2.6.3.8-1](#)).

Basic parameters of this joint shall be selected from the following:

$$c \geq 1,2\max(S_s, S_d); t_{angl}^{out} = 2\max(\delta^d, \delta^s); b_{angl}^{out} \geq 18t_{angl}^{out} \geq 3,5S_s;$$

$$t_{angl}^{in} = 1,2\delta^s; b_{angl}^{in} \geq 15t_{angl}^{in} + c \geq 2S_s; \beta = 45^\circ; l_d = b_{angl}^{in} + s_s + s_d; l_s = b_{angl}^{in} + S_s.$$

Type B. Sandwich deck laminate and side laminate transit to single-skin structures smoothly by bringing load-bearing layers together. Using adhesive, a triangular support element made of the foam plastic of 150 – 200 kg/m<sup>3</sup> in density is installed, and inner and outer moulding-in angles are laid ([refer to Fig. 3.2.6.3.8-2](#)).

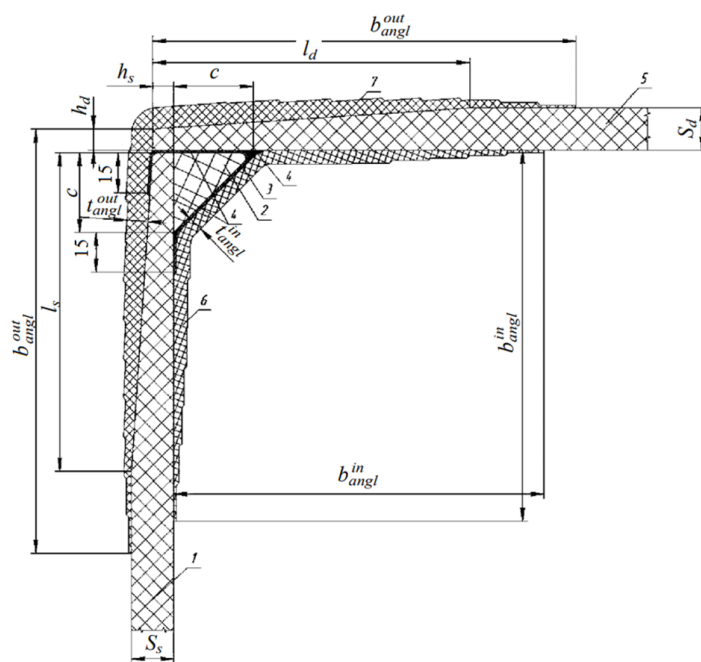


Fig. 3.2.6.3.7

Joint of side and upper deck single-skin constructions of variable thickness, with a support element installed:  
1 – side; 2 – support element; 3 – support element sheathing; 4 – adhesive; 5 – upper deck plating; 6 – inner moulding-in angle; 7 – outer moulding-in angle

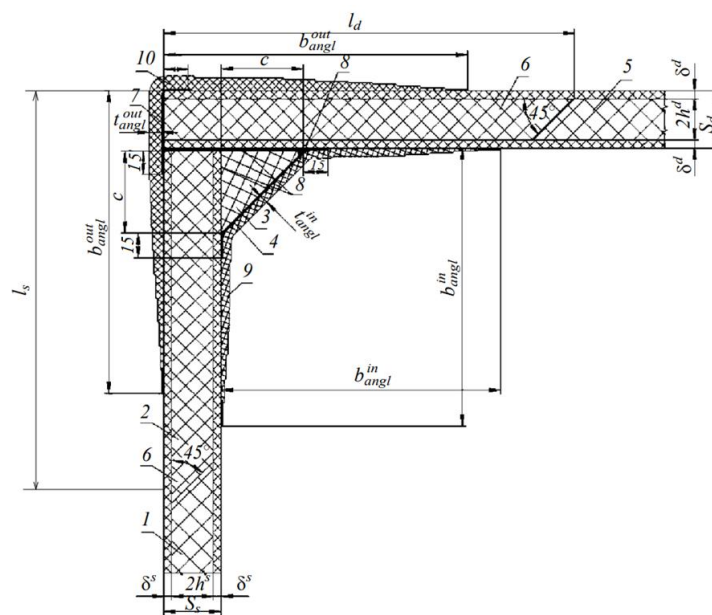


Fig. 3.2.6.3.8-1

Joint of the upper deck plating and side plating of sandwich construction (Type A):  
1 – side laminate; 2 – reinforcement of the foam plastic of increased density; 3 – support element; 4 – sheathing;  
5 – deck laminate; 6 – reinforcement of the foam plastic of increased density; 7 – sheathing; 8 – adhesive;  
9 – inner moulding-in angle; 10 – outer moulding-in angle

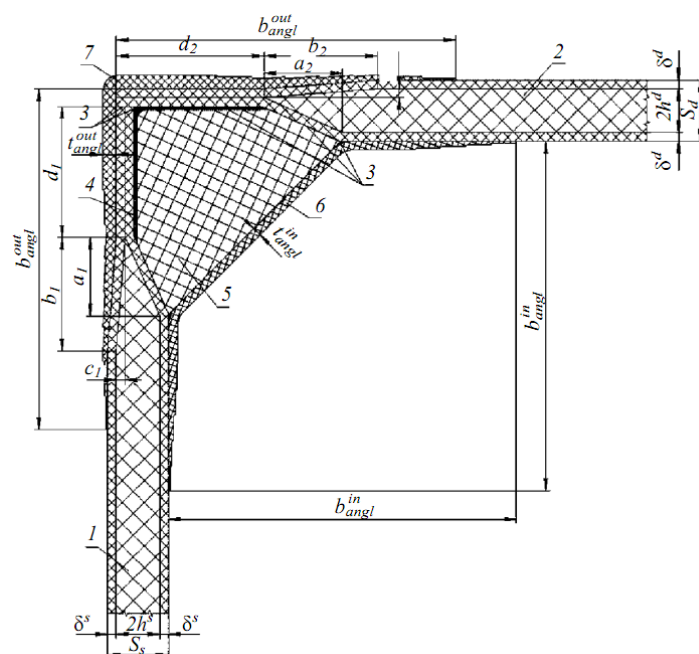


Fig. 3.2.6.3.8-2

Joint of the upper deck plating and side plating of sandwich construction (Type B):

1 – side laminate; 2 – deck laminate; 3 – adhesive; 4 – sheathing; 5 – support element; 6 – inner moulding-in angle; 7 – outer moulding-in angle

Basic parameters of this joint are recommended to be selected from the following:

$$t_{angl}^{out} = 2\max(\delta^d, \delta^s); b_{angl}^{out} \geq 20t_{angl}^{out}; t_{angl}^{in} = 1,2\max(\delta^d, \delta^s); b_{angl}^{in} \geq 18t_{angl}^{in};$$

For both joint types, where the deck and side are provided with a deck stringer and a sheerstrake accordingly, the values of  $\delta^d$ ,  $\delta^s$  specified in the above-mentioned correlations shall be assumed equal to the thicknesses of load-bearing layers of these members;

**.9** inner decks (platforms) are connected to the side plating by means of moulding-in angles and triangular support element made of the foam plastic of increased density of 150 — 200 kg/m<sup>3</sup>.

For examples of joints of the single-skin deck (platform) with the single-skin and sandwich side platings, refer to Fig. [3.2.6.3.9-1](#) and [3.2.6.3.9-2](#).

Basic parameters of these joints shall be selected from the following:

$$c \geq 1,2\max(s_s, s_d); t_{angl} \geq 0,4s_s \text{ or } t_{angl} \geq 2\delta^s \text{ (for the sandwich shell);}$$

$$b_{angl} \geq 15t_{angl} + c \geq 2s_s.$$

Where the inner deck (platform) has a sandwich construction, the joint is made using the same technique.

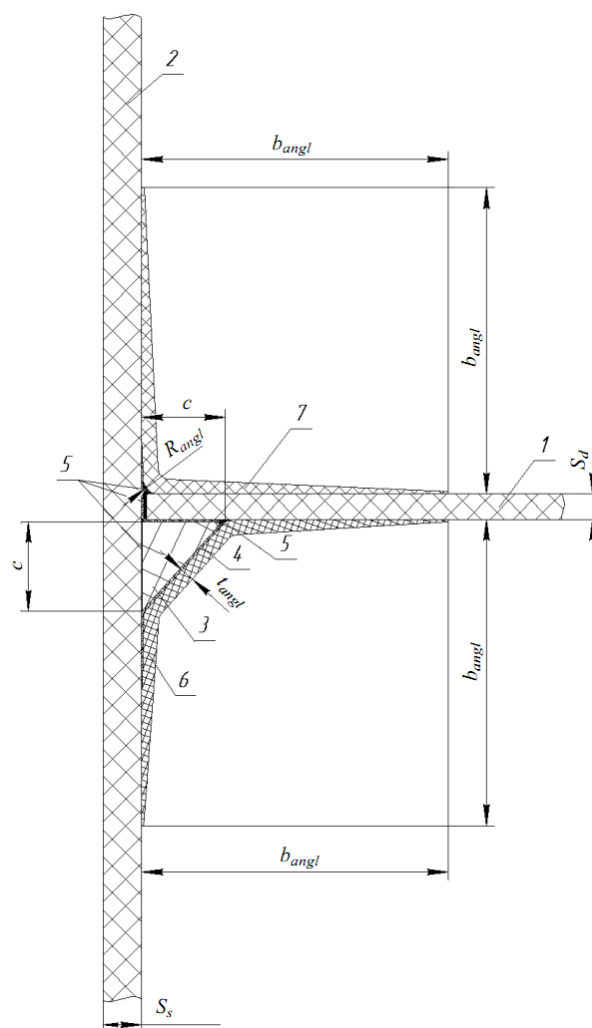


Fig. 3.2.6.3.9-1

Joint of the inner deck (platform) with a single-skin side plating:

1 – inner deck (platform) laminate; 2 – side laminate; 3 – support element; 4 – sheathing; 5 – adhesive; 6 – lower moulding-in angle; 7 – upper moulding-in angle

### 3.2.7 Engine seatings.

**3.2.7.1** Two design types of engine seatings of machinery, equipment and various arrangements installed in the hull may be applied:

- .1 composite – using the materials for hull construction;
- .2 metal – metal elements of the engine seating are connected to composite elements and structural members with fasteners.

**3.2.7.2** The engine seating construction is mainly determined by the characteristics specified for the equipment, machinery and arrangements (weight, operating loads, vibration loads, etc.). In this case, the following shall be taken into account:

members of the FRP engine seatings shall be of solid construction while the number of moulding-in angles and other connecting elements shall be reduced to minimum;

in FRP seatings of heavy machinery and equipment, where bolts pass through the material, metal bushes shall be provided to secure them;

in case of contact forces from the equipment and machinery that may cause the FRP crumpling, provision shall be made for metal straps on the contact surface of the engine seating members and their supports;

when a metal engine seating is designed, a structure of its fastening to hull members shall be considered, which will require fitting metal counterparts and, if necessary, reinforcement of these members.

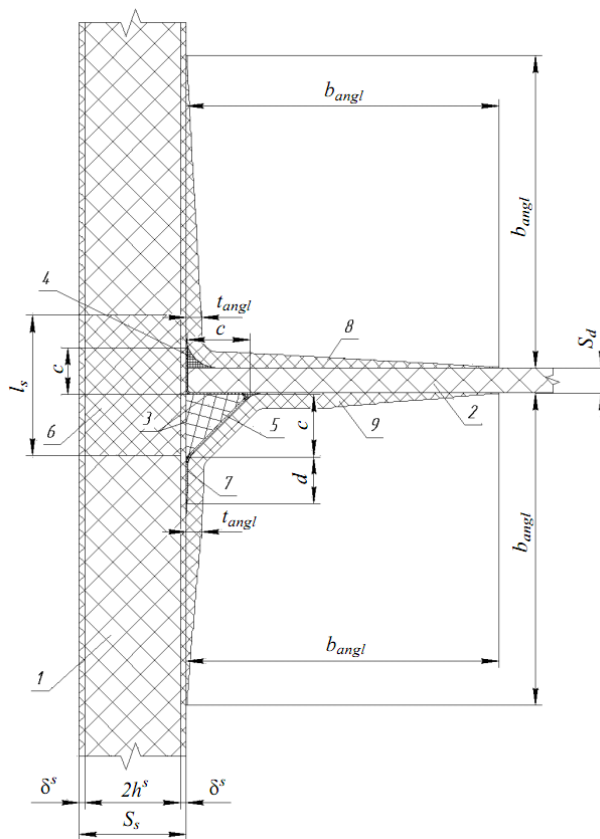


Fig. 3.2.6.3.9-2

Joint of the single-skin inner deck (platform) with a sandwich side plating:

1 – side laminate; 2 – inner deck (platform) laminate; 3, 4 – adhesive; 5 – support element; 6 – reinforcement made of the foam plastic of increased density; 7 – sheathing; 8 – upper moulding-in angle; 9 – lower moulding-in angle

**3.2.7.3** Seatings of main engines and other heavy equipment shall be connected to framing members, e.g. side girders and bulkhead stiffeners, or framing members shall be used for seatings.

Where framing members cannot be used, additional members shall be fitted and connected to main members and terminated considering the requirements of [3.2.4.17](#).

**3.2.7.4** Longitudinals of engine seatings shall be connected with main framing members (stringers) by means of brackets and knees fitted at every frame.

**3.2.7.5** T-shaped section is recommended for girders supporting the foundations of engines and equipment ([refer to 3.1.8](#)).

In this case, girders support elements shall be connected with bolts that attach these elements to a face plate of the member, using metal L-shaped counterparts or moulded metal bushes ([refer to Fig. 3.2.7.5](#)).

**3.2.7.6** Where seating girders are of closed box section, the foam plastic of increased density ( $180 - 250 \text{ kg/m}^3$ ) shall be added to the core, and an additional member as a vertical web made of the same material as the girder sheathing.

These support elements are connected to the girder with metal fasteners and parts. Seating design types with a closed box section girder are shown in [Figs. 3.2.7.6-1 — 3.2.7.6-3](#).

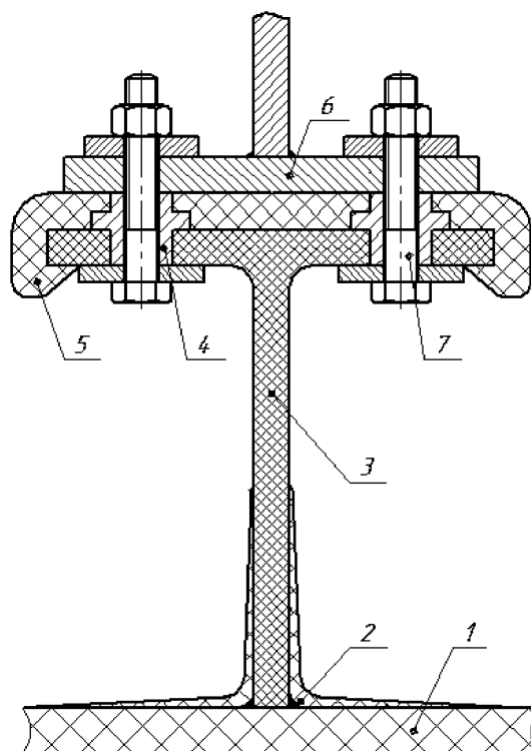


Fig. 3.2.7.5

Joint of a support element of an engine (equipment) to the seating T-shaped section with moulded bushes:  
 1 – shell; 2 – moulding-in angles; 3 – seating girder; 4 – moulded bush; 5 – mould welding; 6 – support element ;  
 7 – bolt

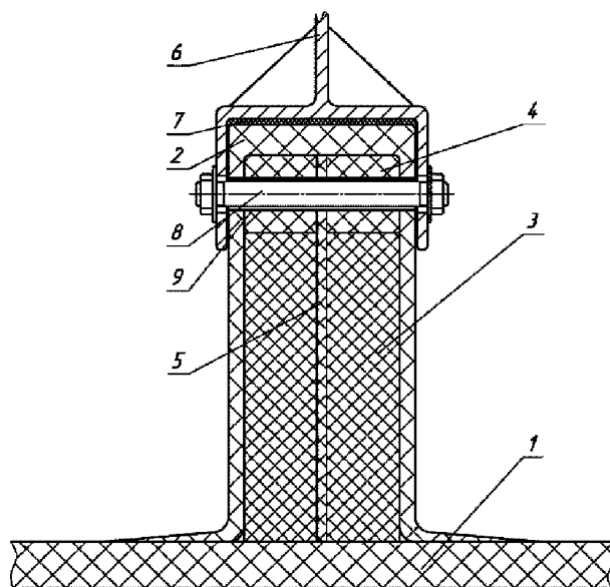


Fig. 3.2.7.6-1

Joint of a support element of an engine (equipment) to the seating closed box section with the use of bolts:  
 1 – shell; 2 – section sheathing; 3 – core; 4 – foam plastic of increased density; 5 – additional web; 6 – support element ;  
 7 – adhesive; 8 – bolt; 9 – bush

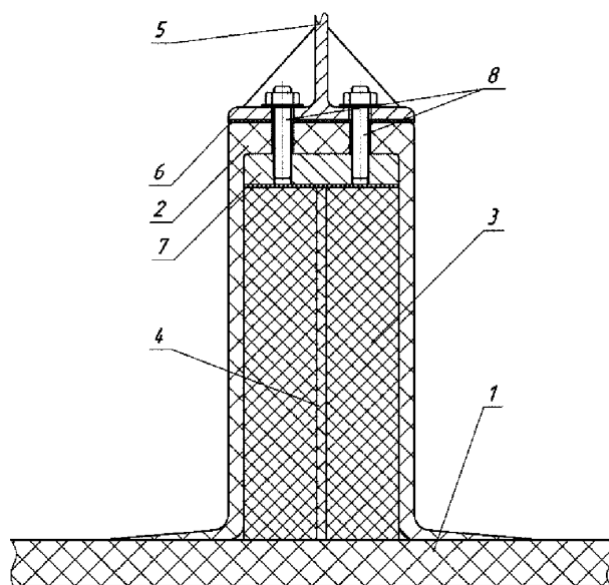


Fig. 3.2.7.6-2

Joint of a support element of an engine (equipment) to the seating closed box section with the use of studs and metal embedded parts:

1 – shell; 2 – section sheathing; 3 – core; 4 – additional web; 5 – support element; 6 – adhesive; 7 – metal embedded part; 8 – studs

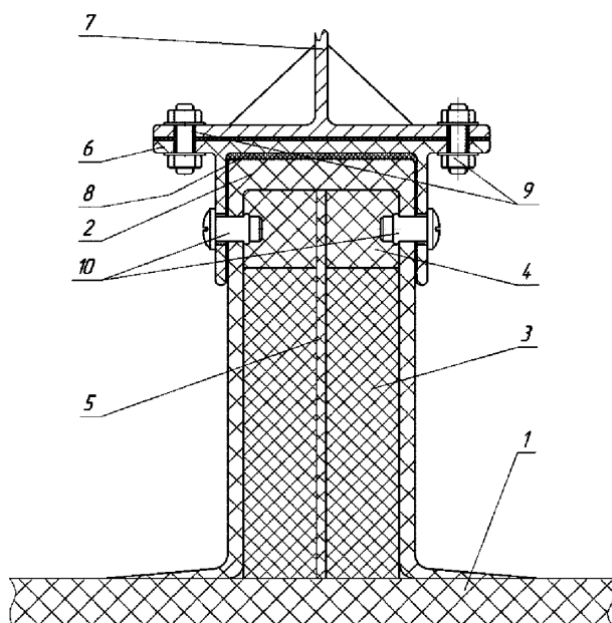


Fig. 3.2.7.6-3

Joint of a support element of an engine (equipment) to the seating closed box section with the use of a closed box flanged element made of FRP, bolts and rivet nuts:

1 – shell; 2 – section sheathing; 3 – core; 4 – foam plastic of increased density; 5 – additional web; 6 – closed box flanged element; 7 – support element; 8 – adhesive; 9 – bolts; 10 – rivet nuts

**3.2.7.7** To fasten main engines, equipment and various machinery to the hull structures, other design types are allowed based on technical background and agreed with the Register.

### 3.2.8 Tanks.

**3.2.8.1** It is recommended, independent tanks that may be made of FRP or aluminium alloys shall be installed in FRP hulls.

**3.2.8.2** In case of hull interior deficiency, it is allowed to install FRP integral tanks with either single-skin or sandwich sides stiffened by framing, where necessary.

Reinforcement scheme, material and structure of the tank shell is determined according to its intended purpose and operation conditions.

**3.2.8.3** As the material for the shell and framing members of integrated tanks, it is allowed to use glass-reinforced plastic based on woven roving or biaxial fiber with reinforcement ( $0^\circ/90^\circ$ ). As a core of the sandwich shell, either PVC foams, PUR foams or lightweight mats may be applied.

**3.2.8.4** Tank shell thickness shall be determined according to the diagrams specified in Figs. [3.2.1.1.7-1](#) and [3.2.1.2.4-1](#), and scantlings of framing members – in accordance with [3.2.4.13](#).

**3.2.8.5** The tank framing and shell shall be manufactured simultaneously within one production process and, where possible, installed outside tanks to prevent it from being separated from the shell.

Hull framing members shall not cross the tank shell, if possible.

**3.2.8.6** The inner surface of tank shell shall have 2 – 3 layers of fabric mesh with increased binder content and properly sealed to avoid leakages.

**3.2.8.7** The construction of tank manholes and covers shall ensure watertightness and strength throughout the ship's service life ([refer to Figs. 3.2.8.7-1 — 3.2.8.7-3](#)).

These requirements are applied to assemblies of fittings in tank sides ([refer to Fig. 3.2.8.7-4](#)).

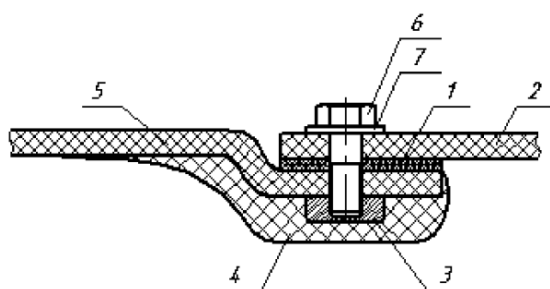


Fig. 3.2.8.7-1

Tank manhole assembled with a cover flush with the shell:

1 – gasket; 2 – cover; 3 – embedded plate; 4 – sheathing; 5 – tank shell; 6 – screw; 7 – washer

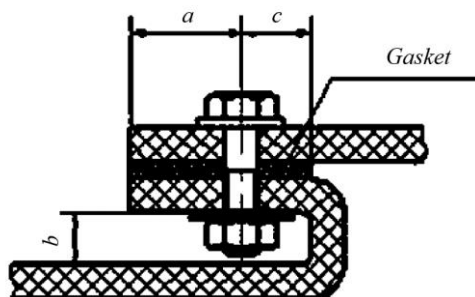


Fig. 3.2.8.7-2

Tank manhole assembly with the flanged shell

$a \geq 3d$ ,  $c \geq 3d$ , where  $d$  – bolt diameter;  $b = 30 - 40$  mm)

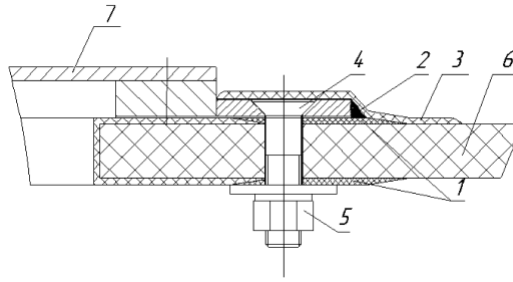


Fig. 3.2.8.7-3

Tank manhole assembly with metal cover:

1 – hole edge sheathing; 2 – adhesive; 3 – matting-in joint; 4 – screw; 5 – nut; 6 – tank shell; 7 – metal cover

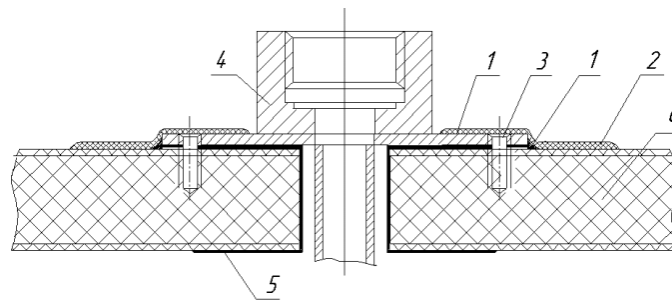


Fig. 3.2.8.7-4

Mounting assembly of the pipeline nipple in the tank shell

1 – adhesive; 2 – matting-in joint; 3 – screw; 4 – nipple; 5 – hole edge sheathing; 6 – tank shell

**3.2.8.8** Fuel oil tanks made of plastic shall be provided with earthing arrangements for discharging static electricity or electrically-insulating coatings in accordance with the requirements of the relevant international or national standards.

### 3.3 STRUCTURE OF SUPERSTRUCTURES AND DECKHOUSES

#### 3.3.1 General.

**3.3.1.1** Superstructures contributing to the longitudinal bending of the ship's hull are referred to superstructures of category I that shall withstand joint effect of loads due to the hull hog and local stresses due to wave impact, motions, equipment weight, etc.

Superstructures of category I are considered to be strong in case the following conditions are simultaneously met:

longitudinal (side) ends and sides of a superstructure shall be jointed to the hull sides or longitudinal bulkheads;

superstructure shall be supported with at least 3 transverse hull rigid members (transverse bulkheads and deck transverses);

superstructure length shall be at least 4 times as much as its depth.

**3.3.1.2** Where the above conditions are not met, a superstructure does not contribute to the longitudinal bending of the ship's hull, is referred to superstructures of category II, which are designed to withstand local loads only as well as deckhouses.

**3.3.1.3** The structure requirements for strong superstructures are the same as for the ship hull. Therefore, structures of main members and assemblies of the hull ([refer to Section 3.2](#)) may be applied to strong superstructures.

Requirements for construction of superstructures, their members and assemblies are specified in [3.3.2](#).

**3.3.1.4** When designing FRP superstructures of ships with metal hulls, particular attention shall be paid to joint of superstructure ends and sides and bulkheads with the hull, which shall ensure strong and reliable joint between the hull and superstructure in all operation modes specified for the ship.

Designs and requirements for these assemblies are specified in [3.3.2](#).

#### 3.3.2 Ends and sides, decks, bulkheads and framing.

**3.3.2.1** It is recommended that end and side plating, decks and bulkhead platings of superstructures and deckhouses shall have a sandwich construction with FRP load-bearing layers and a core, which reduces the number of framing members, ensures thermal insulation of internal spaces and increases their efficient volume due to absence of necessity for sealing and insulation.

**3.3.2.2** The same reinforcing materials as those allowed for ship hulls ([refer to 3.2.1.1 — 3.2.1.2](#)) shall be applied for load-bearing layers of superstructures' sandwich members.

The reinforcement scheme of sides and ends shall have a parallel and diagonal structure  $[(0^\circ/+45^\circ/90^\circ/-45^\circ)]$  by means of several techniques in accordance with [3.2.1.1.3](#) and [3.2.1.1.4](#).

The reinforcement scheme of sides and ends for superstructures of category II and deckhouses is allowed to be parallel  $[(0^\circ/90^\circ)]$  based on woven roving and biaxial fabrics as well as combination products.

The bulkhead reinforcement scheme may be both parallel and parallel and diagonal, depending on the nature of the acting stresses.

Bulkheads of superstructures of category II and deckhouses may be single-skin with a smooth or corrugated plating.

**3.3.2.3** PVC foams or PUR foams and balsa, as well as a structural orthotropic filler with a corrugated element and foam plastic in a space between corrugations are allowed as cores for superstructures of category I ([refer to Fig. 3.2.2.2.5](#)). Characteristics of this filler shall be selected according to [3.2.2.2.5](#) and [3.2.2.2.6](#).

Foam plastic density in the core of sides and ends shall not be less than  $100 \text{ kg/m}^3$ , but not more than  $200 \text{ kg/m}^3$ . If there is a corrugated element in the core, foam plastic of minimum density of  $40 - 50 \text{ kg/m}^3$  is allowed.

For lightweight superstructures and deckhouses, foam plastic of the density not less than  $60 \text{ kg/m}^3$ , but not more than  $100 \text{ kg/m}^3$ , and honeycombs are allowed.

**3.3.2.4** The thickness of load-bearing layers of superstructure sides and ends, decks and bulkheads shall be determined according to [3.2.1.2.4](#) from the diagrams shown in [Fig. 3.2.1.2.4-1](#). In this case, minimum thickness of load-bearing layers of sides and aft walls of strong superstructures shall not be less than 0,8 of the thickness of load-bearing layers of side plating as is shown in [Fig. 3.2.1.2.4-2](#), while the thickness of the fore wall load-bearing layers shall not be less than this thickness. In any case, the thickness of load-bearing layers of superstructure ends and sides shall not be less than 1,8 mm.

**3.3.2.5** For ships with metal hulls, the thickness of load-bearing layers of ends and sides of strong superstructures shall be determined in accordance with [3.3.2.4](#). Where the ship length  $L$  exceeds 70 m, the thickness of load-bearing layers of the superstructure sides shall not be less than 4 mm.

**3.3.2.6** The core thickness of ends and sides of the sandwich construction and of the superstructure top shall be determined subject to compliance with the requirements for heat insulation of internal spaces while structural strength and stiffness are maintained.

Based on this condition, the core thickness shall be not less than 60 – 70 mm.

**3.3.2.7** To reduce the concentration in the structure near the rugged superstructure termination, its sides shall extend beyond ends (front and back), gradually reducing to zero within the length equaling to the superstructure's first tier height.

The bottom strake of superstructure sides near ends shall have layer thicknesses equal to those of the fore web. End parts of sides shall be reliably connected to the hull, using butt straps and moulding-in angles, while fillet edges of free end parts of these sides shall be sheathed to make thickened areas.

Thickness increase and reduction of load-bearing layers of the sides' bottom layer shall be performed in accordance with para [3.2.1.1.8](#).

**3.3.2.8** Superstructure ends and sides, decks and bulkheads shall be stiffened with the use of closed box sections designed as specified in [Fig. 3.2.4.2.1](#).

Member reinforcement materials and schemes, as well as their scantlings shall be selected according to the requirements of [3.2.4.2 – 3.2.4.7](#) and [3.2.4.13](#).

**3.3.2.9** Transverse members (frames, beams, transverse bulkheads) of the strong superstructure shall be arranged in the same plane that coincides with the plane where frames are fitted in the hull.

It is recommended to arrange longitudinal members (stiffeners of the front and back sides, deck girders, longitudinal bulkheads) in the same plane, where deck girders of the ship hull upper deck are arranged.

**3.3.2.10** Where a beam (deck girder) passes through the longitudinal (transverse) bulkhead, the latter shall be strengthened with a stiffener, which may be sniped (refer to [Fig. 3.2.4.25](#)).

**3.3.2.11** Joints of stiffeners to beams and deck girders, and intersections of framing members shall be made taking into account the requirements of [3.2.4.16 – 3.2.4.18](#) and [3.2.4.21 – 3.2.4.23](#).

**3.3.2.12** To enhance stiffness of deck grillages, where the equipment is installed, they shall be stiffened with pillars. Tubular pillars are made of aluminium alloys (AMg) or FRP, which is used for sheathing framing members.

Pillars are fitted on framing members, mainly at their intersections, and secured with metal support elements and bolts, or by means of matted-in angles (refer to Figs. [3.3.2.12-1](#) and [3.3.2.12-2](#)).

Where a pillar is fitted, the foam plastic core in closed box section members shall be substituted with the foam plastic with density not lower than  $200 \text{ kg/m}^3$ , or made with a glued laminated hardwoods (oak, birch, etc.).

### 3.3.3 Joint of superstructure members to the metal hull.

**3.3.3.1** Joint of FRP sides, ends and bulkheads of superstructure with metal hull shall ensure strong and reliable joint between the hull and superstructure, as well as tightness of its internal spaces in all operation conditions of the ship ([refer to 3.3.1.4](#)).

**3.3.3.2** Superstructure sides and ends shall be connected with bonded and bolted joints consisting of a metal coaming with thickness equal to the shell thickness of hull side, a metal attached strip and bolts arranged chequerswise in two rows ([refer to Fig. 3.3.3.2](#)).

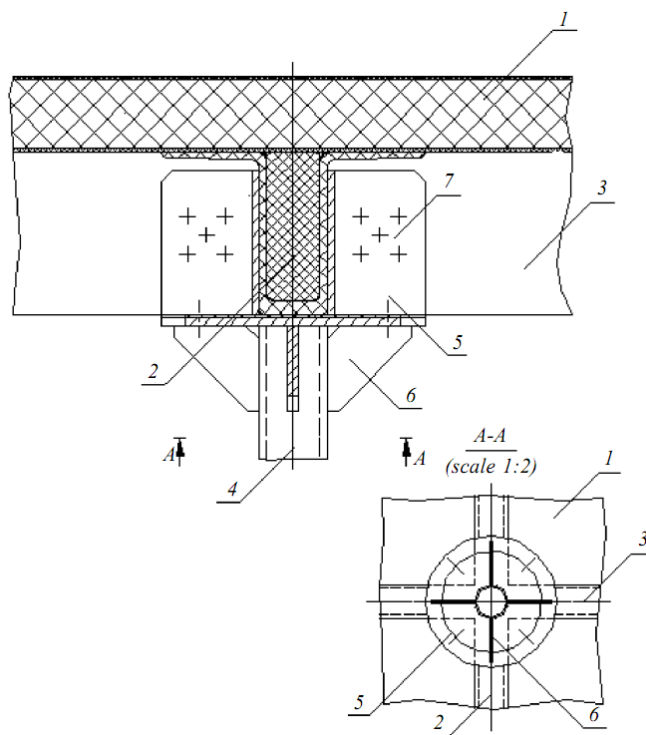


Fig. 3.3.2.12-1

Attachment of the upper end of an aluminum alloy pillar at the intersection of the superstructure beam and deck girder:

1 – deck; 2 – deck girder; 3 – beam; 4 – pillar; 5 – metal casing; 6 – bracket; 7 – bolts

An attached strip shall have thickness of not less than 3 mm, while bolt diameter  $d$  shall be not less than M12. In this case, bolts shall be arranged according to the following ratios:

$$w \geq 2,5d;$$

$$w_1 \geq 3,5d;$$

$$c \geq 3d.$$

Bolt spacing in a row shall be assumed  $t_d \geq 3d$  ([refer to Fig. 3.3.3.2](#)).

A metal coaming, plate and brackets shall be made of the hull metal.

**3.3.3.3** Joint of longitudinal and transverse bulkheads with the hull may be made with a single-row bonded and bolted joint, which consists of a metal coaming, metal attached strip and bolts ([refer to Fig. 3.3.3.3-1](#)), or two metal coamings, with a bulkhead clamped in between with bolts ([refer to Fig. 3.3.3.3-2](#)).

In the first case, the coaming and plate thickness shall be not less than 3 mm, while bolt diameter – not less than M10. In this case, joint parameters shall be as follows:

$$w \geq 4d;$$

$$l_2 \geq 2w.$$

In the second case, the coaming thickness shall be not less than 2 mm.

**3.3.3.4** In these types of joints in the section of sandwich panels of the members arranged between metal elements, the core shall be made of the foam plastic of increased density of  $200 \text{ kg/m}^3$ . Metal elements (coamings, plates) are fitted on load-bearing layers of sandwich panels using adhesive and after drilling are screwed up with bolts and then welded to the hull.

**3.3.3.5** In the joint of superstructure sides and ends to the hull a free space between the coaming and attached strip shall be filled with sealant, while the outer surface of web panels in the coaming location and the coaming itself shall be moulded with 2 – 3 layers of the reinforcing material ([refer to Fig. 3.3.3.3-1](#)).

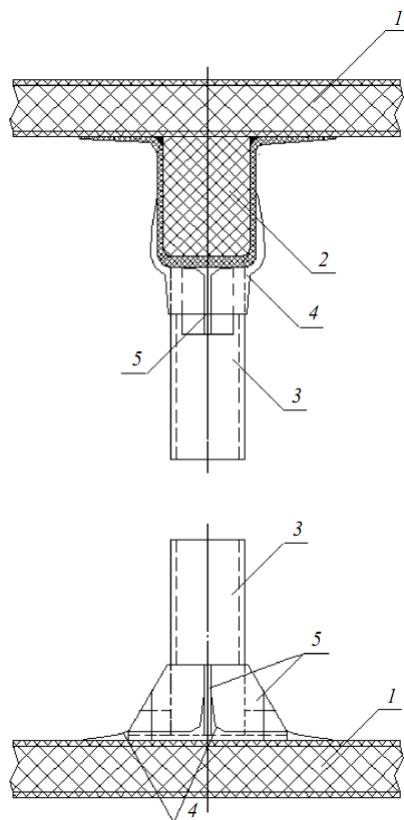


Fig. 3.3.2.12-2

Attachment of the FRP upper and lower ends to superstructure decks:  
1 – decks; 2 – framing member; 3 – pillar; 4 – matting-in joint; 5 – bracket

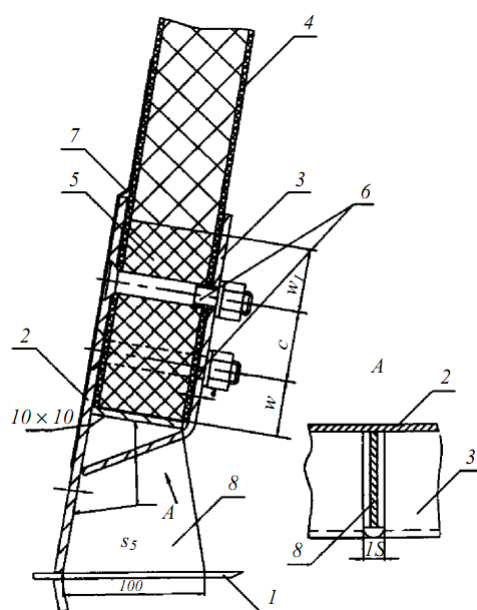


Fig. 3.3.3.2

Bonded and bolted joint of superstructure's side panels to the metal hull:

1 – hull deck; 2 – coaming; 3 – butt plate; 4 – side panel; 5 – foam plastic of increased density; 6 – bolts;  
7 – sheathing; 8 – bracket

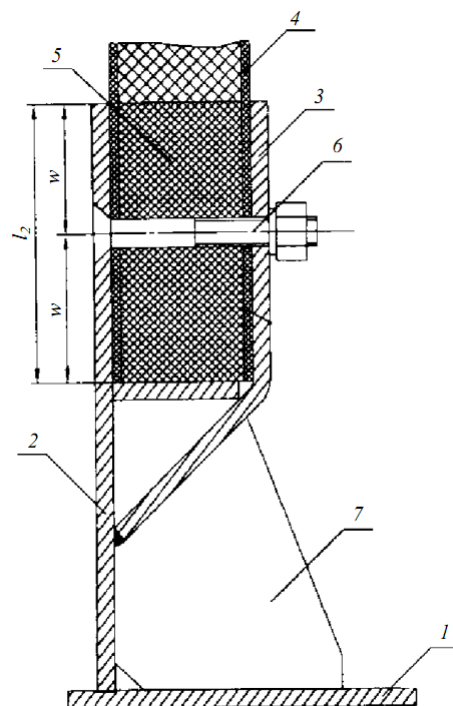


Fig. 3.3.3.3-1

Bonded and bolted joint of the bulkhead to the metal hull (with one metal coaming):

1 – hull deck; 2 – coaming; 3 – butt plate; 4 – bulkhead; 5 – foam plastic of increased density; 6 – bolt;  
7 – bracket

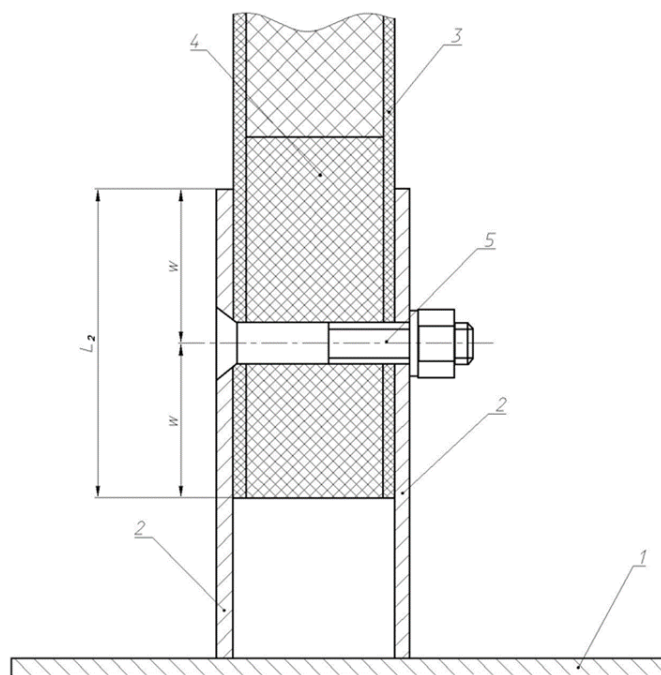


Fig. 3.3.3.3-2

Bonded and bolted joint of the bulkhead to the metal hull (with two metal coamings):  
 1 – hull deck; 2 – coamings; 3 – bulkhead; 4 – foam plastic of increased density; 5 – bolt

## **4 HULLS OF BOATS AND MOTORBOATS**

### **4.1 GENERAL**

**4.1.1** These requirements apply to FRP boats and motorboats of 4,5 – 15 m in length, with the Froude number  $Fr_v < 2,5$  ([refer to 1.1.1.3](#)).

**4.1.2** Where the requirements for scantlings, structures and materials of members and assemblies are not provided in this Section, they shall be determined according to the requirements specified in Sections [2](#) and [3](#).

## 4.2 FRAMING SYSTEMS AND SHELL PLATING

**4.2.1** For hulls of boats up to 10 m and motorboats up to 6 m in length, a transverse framing system is allowed with a centre girder ([refer to Fig. 3.1.3, a](#)) or a centre line box keel fitted.

For hulls of longer boats and motorboats, but not longer than 15 m, mixed longitudinal framing system shall be provided, with framing members arranged longitudinally on the bottom and with frames arranged along sides ([refer to Fig. 3.1.3, b](#)), or with transverse deep members fitted ([refer to Fig. 3.1.3, d](#) and [Fig. 4.2.1](#)).

For hulls of motorboats, transverse redans may be used as longitudinal framing.

**4.2.2** Shell plating of boat and motorboat hulls may be either single-skin or sandwich. In case of a sandwich shell, hulls of up to 8 m in length may be made without framing.

**4.2.3** FRPs based on woven roving and multiaxial fabrics, polyester and vinylester binders shall be used as materials for a single-skin hull shell and load-bearing layers of sandwich shell.

For hulls of up to 8 m in length, either combination products or a mat are allowed. In the latter case, the outer skin surface shall have 2 or 3 woven fabric layers.

**4.2.4** As a core in a sandwich shell, it is allowed to use PVC foams and PUR foams of 60 – 100 kg/m<sup>3</sup> in density or lightweight mats that may be reinforced with fabric layers.

**4.2.5** Reinforcement of the single-skin shell and sandwich shell's load-bearing layers made using woven roving and biaxial fabrics shall have the scheme [(0°/90°)], with 0° direction (warp) positioned along the shell generatrix, or along its directrix. In the latter case, the breaking strength in 90° direction (weft) shall be not lower than the breaking strength in 0° direction (warp), in fabrics with (0°/90°) reinforcement.

**4.2.6** Requirements for butts (seams) and overlaps of reinforcing material layers during moulding of the hull shell correspond to those specified in [3.2.1.1.6](#).

Increase (reduction) of thickness of the shell (load-bearing layers) shall be performed in accordance with the requirements of [3.2.1.1.8](#).

**4.2.7** The thickness of the single-skin shell shall be determined according to the diagrams specified in [3.2.1.1.7](#). In such case, the minimum thickness shall be equal to 3,5 mm.

The thickness of sandwich shell's load-bearing layers shall be determined according to the diagrams specified in [3.2.1.2.4](#). The minimum thickness of the outer load-bearing layer shall be equal to 2,5 mm, and the inner layer – 2 mm.

**4.2.8** The minimum thickness of air cases shell shall be assumed equal to 2 mm. For air cases serving at the same time as seats, the shell thickness shall be increased by 1 mm ([refer to Fig. 4.2.1](#)).

**4.2.9** To increase resistance to sea water exposure and hull finishing the outer hull surface shall have 2 or 3 layers of a net, which ensures high content of binder, and to be gel-coated.

**4.2.10** The side plating shall be connected to the deck or gunwale with bolts or moulding-in angles, according to [3.2.6.3](#).

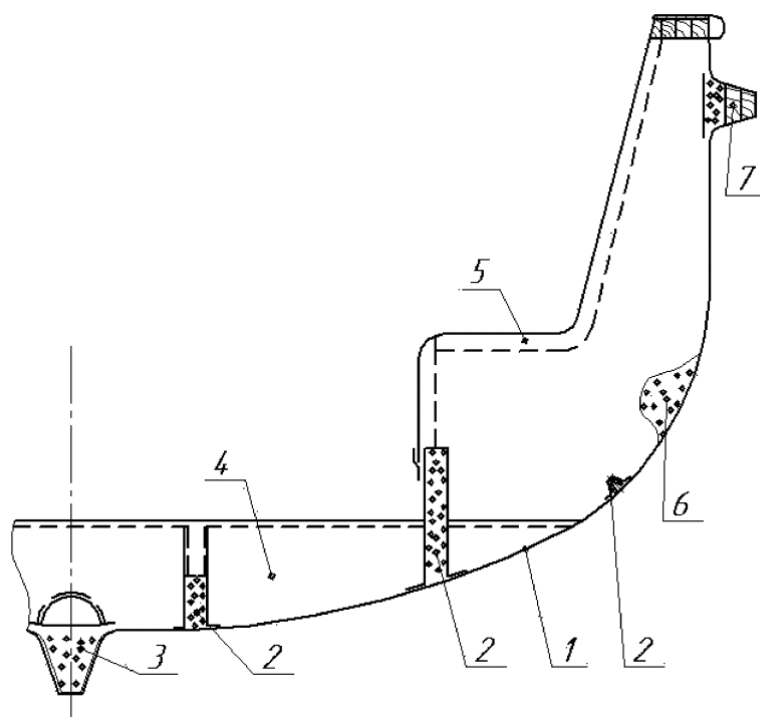


Fig. 4.2.1

Cross-section (midship frame) of the boat hull:

- 1 – shell; 2 – stringers; 3 – centre line box keel; 4 – floor; 5 – cladding of air cases;  
6 – core of air cases (foam plastic); 7 – fender

### **4.3 FRAMING MEMBERS**

**4.3.1** Framing members shall have a closed box (trapezoidal) section with a core of PVC foam of the density not lower than that in the core of the sandwich shell ([refer to 4.2.5](#)).

Where framing members serve as seating members for attachment of engines and equipment, they may have either T-shaped or L-shaped section (refer to [3.1.7](#) and [3.1.8](#)).

For boat hulls up to 8 m, air cases may serve as framing.

**4.3.2** Selection of materials for manufacture of members, reinforcement schemes of their elements, scantlings and forming their connections to the shell and other hull members shall be performed according to the requirements of [3.2.4](#).

**4.3.3** Spacing shall be determined based on condition of ensuring strength considering the necessity to reduce the number of framing members and their intersections.

The minimum spacing shall be 400 mm for a single-skin shell and 800 mm for a sandwich shell.

#### **4.4 ATTACHMENT OF LIFTING GEAR**

**4.4.1** Attachment of the boat hull to lifting gear parts shall ensure launching of a laden boat taking into account the dynamic forces caused due to irregular running of a launching and recovery arrangements, ship motions, wave, etc.

**4.4.2** Attachment shall ensure load transfer to reinforced hull structural members (centre line box keel, web frames, stem, transom) and shall be subject to shear without hull members to be separated from the shell.

**4.4.3** Metal parts of a lifting gear shall be mounted to the hull with bonded and bolted joints. Where they are installed, members shall be additionally reinforced with straps and moulding-in angles.

## **5 HULL STRENGTH AND SUPERSTRUCTURES**

### **5.1 GENERAL**

**5.1.1** Strength calculations of FRP hull structures shall verify set external loads, materials and scantlings of elements and members of these structures, and confirm availability of required strength and buckling strength margins. Such calculations shall be carried out in the following scope:

- .1** determination of values and external load types acting on the hull and their design values;
- .2** standard setting of extreme and permissible stresses ([refer to 5.3](#)) and deformations as well as determination strength and buckling strength margins required for hull members and structures;
- .3** determination of hull member stresses and their deformations;
- .4** verification of strength, stiffness and buckling strength conditions of hull members.

**5.1.2** Strength calculations shall be carried out for the most severe operating conditions when the highest stress level develops in hull members.

**5.1.3** Procedure of strength calculation for the element selection of hull girder shall be as follows:

- determination of the design bending moment and, on its basis, hull girder section modulus; after longitudinal member sections included in the hull girder are selected, determination of stress values developing due to bending moment, at the first approximation;

- determination of reduction factors of plates and the section modulus of the hull girder, at the second approximation;

- determination of stress values in hull members due to the bending moment from the section modulus of the hull girder at the second approximation, and verification whether strength conditions for stresses acting in these members are met.

Where the specified conditions are not met, correction of cross sections of the hull girder longitudinal members shall be carried out followed by recalculation.

**5.1.4** When carrying out strength and buckling strength calculations of hull members and individual FRP structures the following shall be taken into account:

- difference in properties of constituent elements of these members due to application of different materials, their different reinforcement schemes, and different influence of operation conditions;

- shear strains, including both in the reinforcement plane, e.g. in bulkheads, framing webs, etc., and those between layers, especially in sandwich (multi-layered) members;

- breaking stress acting in transverse direction in butt, and especially in angle moulded connections of hull members.

## **5.2 DESIGN LOADS**

**5.2.1** Values of design loads acting on the hull and its individual structures shall be determined regardless of the hull material, according to the RS rules according to which the ship design was approved considering the ship class and operation conditions.

**5.2.2** When determine design loads and strength and stiffness specifications of hull structures, it is necessary to consider the nature and duration of these loads, with regard to FRP physical properties and operation of structures made thereof when exposed to the specified operation conditions.

**5.2.3** According to the approach provided, external loads are divided as follows:  
constant loads, the value and direction of which do not vary or vary slightly over the time;  
variable loads, the amount and/or direction of which vary over the time.  
Constant loads, in their turn, are divided into short-term distributed and long-term distributed, which duration is approximately equal to a ship voyage.

Variable loads are divided as follows:

static variable loads, the whole variation time of which, determined by increase and reduction periods, is three and more times longer than the first mode of structure's natural oscillations;

cyclic static variable loads, which vary repeatedly according to a periodic law;

dynamic loads, the variation time of which is comparable or shorter than the first mode of natural oscillations.

### 5.3 STANDARD EXTREME AND PERMISSIBLE STRESSES AND DEFORMATIONS

**5.3.1** An extreme state of a structure when determine its strength is the state when design deformations and/or stresses in structural members, in their elements, and in layers, if it is a sandwich (multi-layered) structure, achieve critical values when damage may occur and develop further, and the structure may be destroyed, or characteristics of this structure may become non-compliant with performance requirements fully or partially.

**5.3.2** Extreme strength limits (tension, compression, interlaminar shear, etc.) of FRPs, values of which are lower than the expected influence of operation factors (dampening, solar radiation, etc.) throughout the ship service life, and manufacturing technique, are assumed to be extreme stresses.

For members that may lose stability, ultimate Euler stresses are assumed to be extreme stresses. These stresses are determined with account of elastic behaviour anisotropy, the design value of which is also lower than initial values, basing on possible influence of the above factors ([refer to 5.3.5](#)).

**5.3.3** To assign extreme stresses and design values of elastic behaviour, the most unfavorable conditions that may occur during ship operation throughout its service life shall be considered.

**5.3.4** Extreme stresses for members that do not loose stability and exposed to static and static variable loads shall be determined from the following correlations:

$$\sigma_{ij}^u = k\sigma_{ij(\pm)}$$

where  $\sigma_{ij}^u$  = extreme stresses;

$\sigma_{ij(\pm)}$  = initial ultimate tensile (+), compression (–), and shear stresses of the material ( $i, j = 1, 2, 3$ ).

Values of the factor  $k$  considering strength variation of FRPs as a result of moistening, heating, aging influence, and manufacture technique are specified in [Table 5.3.4](#) for various hull members.

**5.3.5** Design values of elastic behaviour are determined from the following ratios:

$$E_{pi} = nE_i, G_{pij} = nG_{ij}$$

where  $E_{pi}, G_{pij}$  = design Young's and shear moduli;

$E_i, G_{ij}$  = design Young's and shear moduli of the material in initial condition ( $i, j = 1, 2, 3$ ).

Values of the factor  $n$  are specified in [Table 5.3.4](#).

**5.3.6** The values of factors  $k$  and  $n$  in [Table 5.3.4](#) are applied to single-skin structures and load-bearing layers of sandwich structures, as well as to framing members made of FRPs with the use of closed moulding techniques. When applied to a core of sandwich structures and closed box sections, values of factors  $k$  and  $n$  shall be reduced by 0,05.

When a contact moulding technique is used for manufacture of hull structures and their individual elements, factor  $k$  shall be reduced by 0,1, and factor  $n$  – by 0,05.

**5.3.7** Values of permissible stresses are assigned as portion of extreme stresses, which is determined from required strength margins:

for normal stresses  $\sigma_{ii} = k_n\sigma_{ii}^u$  ( $i = 1, 2$ );

for shear stresses  $\sigma_{ij} = k_c\sigma_{ij}^u$  ( $i, j = 1, 2, 3, i \neq j$ ).

Values of factors  $k_n, k_c$  are specified in [Table 5.3.7](#), depending on the nature of external loads acting on the hull.

Table 5.3.4

**Values of factors  $k$  and  $n$  used to determine ultimate stresses and design values of elastic behaviour**

| Hull member                     | $k$  | $n$  |
|---------------------------------|------|------|
| Upper deck plating (exposed)    | 0,55 | 0,80 |
| Deck stringer plate             |      |      |
| Deck framing                    | 0,70 | 0,90 |
| Intermediate decks, platforms   | 0,70 | 0,90 |
| Transverse watertight bulkheads | 0,70 | 0,90 |
| Bulkhead stiffeners             | 0,70 | 0,90 |
| Side plating above waterline    | 0,65 | 0,85 |
| Sheerstrake                     |      |      |
| Side plating below waterline    | 0,60 | 0,80 |
| Bottom plating plate keel       |      |      |
| Side and bottom framing         | 0,65 | 0,85 |

Table 5.3.7

**Values of factors  $k_n$  and  $k_c$  used to determine permissible stresses**

| External loads                    | $k_n$ | $k_c$ |
|-----------------------------------|-------|-------|
| Continuous, static variable loads | 0,6   | 0,5   |
| Accidental, emergency loads       | 0,8   | 0,7   |
| Loads due to equipment weight     | 0,6   | 0,6   |

**5.3.8** Deformations are rated depending on the condition that limits work of the member in the linear range, and based on its strength requirements due to performance reliability of ship equipment and systems.

When being calculated, member strains are included in the calculation together with their design elastic parameters determined according to 5.3.5. A component associated with transverse shear shall be considered (refer to 5.1.4).

**5.3.9** Permissible deflections of hull structural members are determined by the formula

$$[w] = k_w^{-1} l_p$$

where  $l_p$  = design member span (the smallest side of the plating support contour, ship hull length between perpendiculars).

Values of the factor  $k_w$  are taken as follows:

for hull shell plating (deck plating)  $k_w = 80$ ;

for longitudinal framing members (stringers, deck girders)  $k_w = 100$ ;

for transverses (floors, frames, beams)  $k_w = 80$ ;

for the ship hull as a whole  $k_w = 300$ .

For structural members exposed to emergency loads, the following standard deflections are specified:

for hull shell plating (bulkhead panels)  $k_w = 50$ ;

for framing bulkheads, including bulkhead stiffeners  $k_w = 80$ ;

for the ship hull as a whole  $k_w = 250$ .

**5.3.10** When calculating structural members for buckling strength, the margin is assigned relative to ultimate Euler forces or stresses. In all cases, the stability margin shall be not less than 1,5.

Recommendations for assignment of buckling strength margins for individual members are specified below.

## 5.4 LONGITUDINAL HULL STRENGTH

**5.4.1** Longitudinal hull strength calculation shall include verification using the following:  
 permissible normal and shear stresses;  
 permissible deflections of longitudinal members and hull as a whole;  
 relevant buckling strength margins for longitudinal members.

**5.4.2** Design values of sagging and hogging bending moments and shear forces are determined for the specified operational conditions, and for the least favourable loading conditions.

Design values of sagging and hogging bending moments and shear forces are determined as a sum of still water hull bending component  $M_{sw}$ ,  $N_{sw}$  and a wave component  $M_w$ ,  $N_w$ :

$$M_T = M_{sw} + M_w;$$

$$N_T = N_{sw} + N_w.$$

For high-speed craft, dynamic component  $M_d$ ,  $N_d$  due to hydrodynamic pressure caused by wave impact shall be determined in addition to the design values specified.

Values  $M_{sw}$ ,  $M_w$ ,  $N_{sw}$ ,  $N_w$ , as well as  $M_d$  and  $N_d$  are determined in accordance with the Part II Rules and Part II "Hull Structure and Strength" of the Rules for the Classification and Construction of High-Speed Craft.

**5.4.3** Longitudinal hull strength shall be checked for transverse sections exposed to the most unfavorable factors such as maximum permissible loads, location in the areas of abrupt change of stiffness, i.e. locations of large openings, etc.

Longitudinal hull strength calculations are performed for the midship and sections with maximum shear forces, as well as in locations of openings in the upper strength deck, of the width  $B \geq 0,2 B$ , where  $B$  – deck width in the section under consideration, and in the section where a forecastle terminates.

**5.4.4** When determine the hull girder characteristics, reduction factors for hull members shall be calculated to considering the difference in their design elastic response ([refer to 5.1.4](#)), and structural features of these members.

For an  $n$ -th member, the reduction factor value is determined from the following formula:

$$\psi_n = (E_{1p})_n / (E_{1p})_0$$

where  $(E_{1p})_n$  = Young's modulus of the  $n$ -th member along the hull (direction of axis 1);

$(E_{1p})_0$  = Young's modulus of the  $n$ -th member along the hull assumed to be the main one, relative to one the  $n$ -th member geometry is reduced, e.g. Young's modulus of the bottom plating.

**5.4.5** When determine hull girder, longitudinals (stringers, deck girders, and continuous side coamings) are calculated if the following conditions are met:

longitudinal length exceeds the midship side depth;

longitudinal ends are fitted at least two spacings from the hull cross-section calculated.

**5.4.6** When determine hull girder elements, the cross-sectional area of the deck in the section where the opening of the width  $B_o \geq 0,2 B$  is located ([refer to 5.4.3](#)) shall be decreased by the cross-sectional area of the deck in the opening. The openings located in the same section and spaced from each other to the distance (as measured between their edges) less than 1,5 of the smallest opening width is considered to be one opening of the width equal to the sum of widths of all openings located in the section under consideration.

In this case, mean values of design stresses in the deck around the opening are determined from the formula

$$(\sigma_{11})_{deck} = \frac{M}{10(W_o)_{deck}} \psi_{deck}$$

where  $M$  = value of the bending moment acting in the design section, in kNm;  
 $(W_o)_{deck}$  = section modulus of the deck, calculated with account of an opening, in cm<sup>2</sup>m;  
 $\psi_{deck}$  = reduction factor of the deck determined according to [5.4.4](#).

Where the deck (or another member) has a sandwich construction with load-bearing layers of thickness  $\delta_i$  ( $i = 1, 2$ ) and core of thickness  $2h$ , its reduction factor  $\psi_{deck}$  is determined by the formula

$$\psi_{deck} = (\psi_{ll} + \gamma \psi_{core}) / (1 + \gamma)$$

where  $\gamma = 2h / (\delta_1 + \delta_2)$ ;  
 $\psi_{ll}, \psi_{core}$  = reduction factors determined according to [5.4.4](#), for load-bearing layers and cores accordingly.

**5.4.7** When determine hull girder elements in the deck with the opening of width  $0,2B$ , a deck part beyond the opening shall be excluded from its cross-sectional area ([refer to Fig. 5.4.7](#)).

**5.4.8** Where the opening is stiffened by thickening the deck plating (load-bearing layers) or by fitting of the coaming according to [3.2.5](#), the remaining cross-sectional area of the deck ([refer to 5.4.6](#)) shall be enlarged by the cross-sectional area of the members stiffening the opening.

**5.4.9** Where  $B_o < 0,2 B$  in the deck section under consideration, the opening may not be considered when determine hull girder elements.

In this case, mean values of design stresses in the deck around the opening shall be determined by the formula

$$(\sigma_{11})_{deck} = \frac{M}{10W_{deck}} \frac{F_{deck}}{(F_o)_{deck}} \psi_{deck}$$

where  $W_{deck}$  = section modulus of the deck in the section under consideration, opening not considered, in cm<sup>2</sup>m;  
 $F_{deck}$  = cross-sectional area of the deck, opening not considered, in cm<sup>2</sup>;  
 $(F_o)_{deck}$  = cross-sectional area of the deck, opening not considered, in cm<sup>2</sup>.

**5.4.10** The superstructure is considered when determine hull girder elements if its length exceeds the depth of hull girder elements by 4 times and more, and/or hull girder elements are supported by at least three transverse bulkheads. In such case, in superstructure termination areas its longitudinal members shall be determined according to [Fig. 5.4.10](#).

Deckhouses shall not be considered when determine hull girder elements.

**5.4.11** All members ensuring longitudinal strength of the ship's hull and exposed to the local load shall be verified using combined normal stresses.

These members primarily include bottom members, for which the local load is water pressure  $p$  determined by the following formulae:

$$p = \rho g H \cdot 10^{-3}$$

where  $p$  = water pressure, in MPa;  
 $\rho = 1,025 \text{ t/m}^3$  – sea water density;

$g = 9,81 \text{ m/s}^2$  – gravity acceleration;

$H$  = height of water column determined from the formula

$$H = T + h/2 - z, \text{ in m}$$

where  $T$  = midship draft, m;

$h$  = design wave height, in m, (refer to 4.2);

$z$  = distance of the member under consideration from the main surface, in m.

**5.4.12** The hull strength for shear stresses shall be verified for the side plating and plating of longitudinal bulkheads by the following formula:

$$\sigma_{12} = \frac{N_p S}{J s_z} \leq [\sigma_{12}] = 0,8 \sigma_{12}^o,$$

where  $N_p$  = refer to 5.4.2;

$s_z = 2 \sum_{n=1}^m s_n$  – total thickness of the side plating and plating of longitudinal bulkheads arranged on the same side from a centreline (if they are arranged symmetrically);

$S$  = actual statical moment, about the neutral axis, of the hull's cross-sectional area part located above (or below) the horizontal plane, where shear stresses are determined;

$J$  = moment of inertia of the hull cross-section calculated relative to the neutral axis.

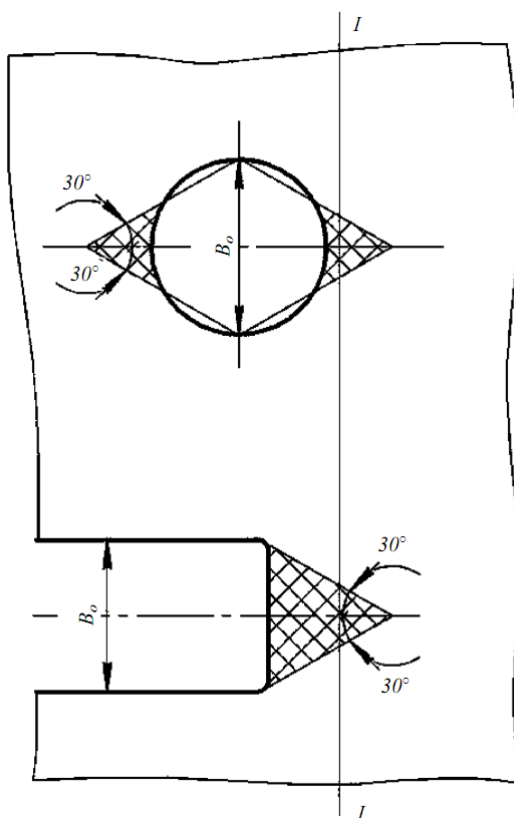


Fig. 5.4.7

Deck areas (hatched) not considered in the design cross-section ( $I - I$ ) when determine hull girder elements

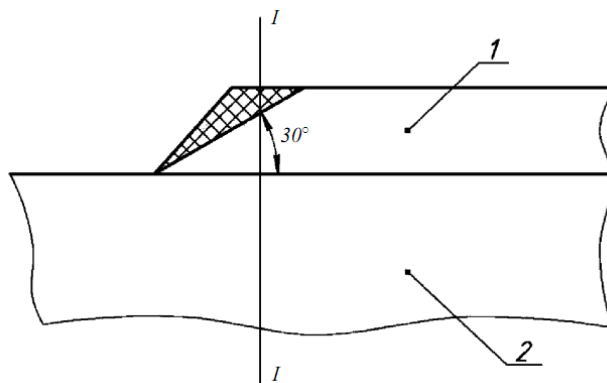


Fig. 5.4.10

Superstructure area (hatched) not considered in design cross-section ( $I-I$ ) when determine hull girder elements:  
 1 – superstructure; 2 – hull

When determine  $s_x$ , thicknesses of members and their layers are calculated considering reduction factors ([refer to 5.4.4](#)). In such case, Young's moduli  $E_{1p}$  shall be substituted with shear moduli  $G_{p12}$ ;  $\sigma_{12}$  shall be assumed as the stress value in the member (or a load-bearing layer), relative to which the reduction is made.

**5.4.13** When determine the longitudinal strength of the hull, its maximum deflection under design forces shall be determined ([refer to 5.4.2](#)). The maximum deflection determined with consideration of shear shall not exceed the permissible level specified in [5.3.8](#).

**5.4.14** When the longitudinal strength is verified for buckling strength of longitudinal members shall meet the following conditions:

centre girder, stringer, deck girders, deck stringer plate and sheerstrake shall not lose buckling strength until the stresses are equal to three-fold design ones (considering combined stresses) or to extreme ones, whichever is lower;

plates of the bottom skin or upper (strength) deck shall not lose buckling strength until the stresses are equal to two-fold design ones (considering combined stresses) or to extreme ones, whichever is lower;

side plates under shear shall not lose buckling strength until the stresses are equal to two-fold design ones.

## 5.5 LOCAL HULL STRENGTH

**5.5.1** Main hull structures (bottom, sides, decks, bulkheads, superstructure) shall be designed to withstand all the loads occurring under operational and emergency conditions.

Design loads shall be determined in accordance with the relevant Sections of the RS rules that regulates the hull strength and according to which the ship design was approved.

**5.5.2** When determine grillages, frames, continuous members the following shall be taken into account:

design span length  $l_p$  of the member as part of the grillage or frame is assumed equal to the distance between intersections with neutral axes of adjacent members of the same direction or members of the opposite directions, if they may be considered as supports, or equal to the distance between bulkheads, decks, etc.;

when statically indeterminate continuous members are calculated, brackets in bearing sections are not considered;

member of a variable cross-section shall be calculated as the first approximation, with the depth and area equal to minimum values of these parameters for the first member; if strength and stiffness requirements are not satisfied upon this calculation, the member shall be calculated at the second approximation, with actual variation of its cross-section taken into account;

**5.5.3** When calculating grillage members, the width of the attached plate  $\bar{b}_{ap}$  the hull and deck plating adjoining the members shall be determined from the following ratio:

for longitudinals (stringers, deck girders):

$$\frac{1}{6}L_p \geq \bar{b}_{ap} = B_p + \frac{1}{2}(b_f^r + b_f^l) \frac{(E_{p1})_{fp}}{(E_{1p})_{ffp}}$$

for transverses (floors, beams):

$$\frac{1}{6}L_p \geq \bar{b}_{ap} = B_b + 1_f \frac{(E_{p2})_{fp}}{(E_{2p})_{ffp}}$$

where  $L_p$  = design span length of the member determined for members according to [5.5.2](#);  
 $b_f^r, b_f^l$  = distance between longitudinals (transverse spacing) to the right and to the left from the member calculated;  
 $l_f$  = distance between transverses (longitudinal spacing);  
 $B_b$  = width of the closed box stiffener section in the foundation; if the member has a T-shaped section, then  $B_b = 0$ ;  
 $(E_{pj})_{fp}$  = design Young's modulus ([refer to 5.3.5](#)) of the attached plate of the hull shell (deck) along ( $j = 1$ ) and across ( $j = 2$ ) the hull;  
 $(E_{pj})_{ffp}$  = design Young's modulus of the attached plate of the member calculated.

When determine the centre girder strength, the width of the attached plate is assumed equal to the full width of a plate keel multiplied by the reduction factor

$$\psi = \frac{(E_{p1})_{fp}}{(E_{1p})_{ffp}}.$$

**5.5.4** When determine the members strength weakening of their webs with openings for members of different direction shall be taken into account ([refer to 3.2.4](#)).

**5.5.5** The hull shell strength shall be calculated for the water hydrostatic pressure impact, the value of which is determined in accordance with the RS rules according to which the ship design was approved

The design load on shell plating is considered to be uniformly distributed. Bottom platings supported with the support contour formed with stringers (centre girder and stringer) and floors are considered to be fixed.

For side plates, the support contour of which is formed with frames, decks and a bilge plate, fixing along vertical plates edges and free support of its horizontal edges are used. The values of the uniformly distributed load acting on the side plate is assumed equal to the mean value of intensity of the loads acting at the levels of its lower and upper horizontal edges.

**5.5.6** Hull plating at the fore end shall be verified for the hydrodynamic pressure under the wave impact upon the bottom of the fore end, the value of which shall be determined according to 2.8.3.2, Part II "Hull".

**5.5.7** Longitudinal strength and buckling strength of bottom grillage shall be determined upon uniformly distributed transverse load equal to the hydrostatic pressure value, and the forces acting in the grillage plane due to longitudinal bending from side grillages loaded with the water pressure.

When determine longitudinal strength, floors are considered to be freely supported, stringers and centre girder fixed on transverse bulkheads. When lengths of adjacent compartments or values of the loads they are exposed to are considerably different from each other, the factor of matched supporting longitudinals on bulkheads is determined by the following formula:

$$\alpha = \frac{1 + \frac{1}{2} \frac{\bar{p}}{p} \left( \frac{\bar{L}_p}{L_p} \right)^3}{1 + \frac{1}{2} \frac{\bar{L}_p}{L_p}}$$

where  $\bar{p}$  = average/mean intensity of the transverse load in two compartments adjacent with the grillage calculated;  
 $p$  = intensity of the transverse load acting on this grillage with the design length  $L_p$ ;  
 $\bar{L}_p$  = average design length of two adjacent compartments.

**5.5.8** The bottom grillage supporting the side grillages and bulkheads shall be verified using maximum loads transferred from the structures specified. In this case, the following buckling strength margins  $k_y$  relative to acting stresses or forces shall be ensured:

for longitudinals  $k_y = 2,0$ ;

for transverses  $k_y = 1,5$ ;

When determine buckling strength at the first approximation, frame grillages may be considered as isolated with attached plate calculated according to [5.5.3](#).

Where the above-mentioned buckling strength requirements are not complied with, the entire grillage shall be calculated.

**5.5.9** The buckling strength check of bottom grillage members shall be mandatorily included in the buckling strength check in simple bending for T-shaped section webs and local buckling strength for closed-box section webs. In both cases, the buckling strength margin shall be  $k_y \geq 1,5$ .

**5.5.10** The side grillage strength shall be calculated for the action of the hydrostatic pressure over the side depth according to the trapezoidal rule.

Frames are considered as continuous members freely supported on the upper deck and bilge plate. The design length of frames shall be determined according to [5.5.2](#).

Where this requirement for permissible stresses is not complied with upon calculation of frames as continuous members, a transverse frame ring shall be calculated, including the bottom floor, upper and intermediate deck beams and frames.

**5.5.11** The side grillage buckling strength shall be calculated for compression and shear. In this case, the buckling strength margin shall be  $k_y \geq 1,5$  relative to maximum forces transferred to the grillage calculated from the side of supporting decks, platforms, transverse bulkheads and bottom grillage.

**5.5.12** Frames and bottom framing at the fore end shall be designed to withstand hydrodynamic under the wave impact upon the bottom of the fore end.

Pressure shall be determined in accordance with the relevant Sections of the RS rules that regulates the hull strength and according to which the ship design was approved.

**5.5.13** The strength of the upper deck, as well as intermediate decks and platforms shall be verified for service loads:

pressure due to wave impact on the upper deck;

weight of the cargo accommodated on decks and platforms, including inertial forces under conditions of the ship motions;

The load due to wave impact and design values of the inertial component based on amplitudes and periods of rolling and pitching as specified in the design documentation shall be determined in accordance with the relevant Sections of the RS rules that regulates the hull strength and according to which the ship design was approved.

**5.5.14** Buckling strength of decks and platforms shall be checked under maximum forces due to longitudinal bending and those transferred from side supporting grillages and bulkheads.

The buckling strength margin is assumed equal to:

$k_y = 2,0$  – for deck girders;

$k_y = 1,5$  – for beams.

Framing members of decks and platforms shall be mandatorily checked for buckling strength in simple bending and local buckling strength of closed box section webs ([refer to 5.5.9](#)).

**5.5.15** Watertight bulkheads shall be checked for strength when exposed to flooding head, which value shall be determined in accordance with the relevant Sections of the RS rules that regulates the hull strength and according to which the ship design was approved.

The strength of decks and platforms shall be checked for the same load if they ensure water-tightness of ship compartments in case of their emergency flooding.

**5.5.16** All bulkheads, which serve as supports for deck, side and bottom grillages shall be verified by calculation using maximum loads due to bidirectional compression and shear in the bulkhead plane. In this case, the buckling strength margin not less than  $k_y = 1,5$  shall be ensured.

**5.5.17** The local vibration and strength of the after end exposed to vibration loads shall be checked separately.

## 5.6 STRUCTURAL STRENGTH OF SUPERSTRUCTURE

**5.6.1** Where the superstructure contributes to the longitudinal bending of the hull, its longitudinal members (sides, decks, longitudinal bulkheads) shall be calculated using forces under the hull longitudinal bending, and local loads due to wave impact and the equipment, machinery and other cargoes in the superstructure, including the crew.

**5.6.2** Forces acting in longitudinal members of the superstructure contributing to longitudinal bending may be determined by the following formulae:

for sides and longitudinal bulkheads

$$T_{in} \approx \frac{\sigma_{ok}}{E_{ok}} A_{ii};$$

for deck girders

$$T_k \approx \frac{\sigma_{ok}}{E_{ok}} A_k$$

where  $\sigma_{ok}$  = stress in the main hull on the upper deck level;  
 $E_{ok}$  = Young's modulus (or reduced modulus) of the main hull material;  
 $A_{ii}$  = reduced axial stiffness of the of the plate specified members in the longitudinal direction;  
 $A_k = \sum A_j$  – reduced axial stiffness of the deck girder with an attached plate ([refer to 5.5.3](#)).

**5.6.3** The value of the load acting on superstructure sides shall be determined according to the requirements of the RS rules to which the ship design was approved.

Sides of the second tier superstructures shall be checked using loads equal to 50 % of the loads acting on relevant sides of the first tier.

**5.6.4** Where the superstructure members (deck, bulkhead, etc.) accommodate the equipment, these members shall be additionally determined using local or concentrated loads according to the formula

$$P_p^M = k_d^M M$$

where  $M$  = weight of the equipment installed;  
 $k_d^M$  = dynamic factor that shall be not less than  $k_d^M \geq 2$  and is specified in the ship's project documentation.

**5.6.5** When calculating the strength of superstructure (deckhouse) members for plates and framing members, factors  $k_n$ ,  $k_c$  to determine permissible stresses ([refer to 5.3.7](#)) are assumed equal to  $k_n = 0,7$ ,  $k_c = 0,8$  regardless of the acting load.

In superstructure members contributing to the longitudinal bending stresses due to longitudinal hull bending and local load impacts shall be summarized.

**5.6.6** The check of superstructure (deckhouse) members for buckling strength shall ensure the buckling strength margin not less than  $k_y \geq 1,5$ .

**5.6.7** The joint strength of the superstructure sides and the hull at superstructure ends shall be checked separately for shear and tear stresses. In this case, factors  $k_n$ ,  $k_c$  shall be assumed  $k_n = k_c = 0,6$ .

**5.6.8** Plates of sides, decks and superstructure bulkheads shall be calculated as freely supported and/or fixed to the support contour. The support contour for plates of sides, fore and back ends are formed with horizontal members, which include the upper deck of the hull, intermediate decks of the superstructure and its top, and with vertical members, including bulkheads and frames (stiffeners). Support members for deck plates are ends and sides, bulkheads, beams and deck girders.

Plates of sides, fore and back ends and those of decks and top are considered to be fixed along all four edges, excluding side and top plates attached to each other along one of the edges. In these plates, edges supporting each other are considered to be freely supported, and other edges to be fixed.

**5.6.9** Where the equipment is installed on the deck, the deck plate is calculated as freely supported on all four edges under local or concentrated load determined according to [5.6.4](#). Determined stresses in plate elements are summarized with those in the same elements exposed to the uniform load.

**5.6.10** The strength and stiffness of framing members (frames, beams, deck girders and stiffeners) shall be determined when exposed to the loads specified in [5.6.3](#) and [5.6.4](#).

If frames and beams are aligned and form a frame or semi-frame, these frames and beams shall be determined as elements of the frame with fixed and/or flexible joints.

Otherwise, frames and beams, as well as deck girders and stiffeners, shall be considered as single-span (or multi-span) beams with fixed or freely supported ends. In the latter case, a frame terminates without changing in its plane to another member, e.g. a bulkhead.

The supports are:

for frames and stiffeners of the fore and back webs – decks and top;

for beams – sides, longitudinal bulkheads, pillars;

for deck girders – fore and back ends, transverse bulkheads, pillars.

**5.6.11** When determine the geometric and stiffness characteristics of the framing member, the width of the attached plate of a plate is assumed (whichever is less) equal to  $1/6l_d$  or  $7H$  in case of a laminate of sandwich construction (where  $l_d$  is design span length,  $H$  is total thickness of a sandwich laminate).

Design span length  $l_d$  is assumed equal to the distance between intersections of the neutral axis of the member calculated and planes passing through neutral axes of the members, or middle surfaces of member (side, bulkhead, etc.) plates it crosses.

**5.6.12** When determine framing members, cross-section variability around support attachments due to brackets installed or section depth variability where the member is jointed to the crossing member, shall not be considered. The frame curvature shall not be considered either, unless it exceeds 20 %.

**5.6.13** Sandwich laminates of sides and ends, decks, bulkheads, etc., and their framing shall be verified for longitudinal and local buckling strength when exposed to the most unfavorable load combination. In such case, the local buckling failure means:

in sandwich laminates – buckling failure of load-bearing layers;

in members – buckling failure of sides and ends for closed box section (simple bending for T-shaped sections).

The local buckling strength margin shall be not less than  $k_y \geq 1,5$  relative to design stresses acting in load-bearing layers and webs of the closed box section accordingly.

**5.6.14** Plates of superstructure's side webs, and of longitudinal bulkheads, shall be verified for buckling strength when exposed to joint action of the highest loads due to longitudinal bending and forces from the loads acting on the above structures, their weight, and weight of the equipment installed thereon. The longitudinal buckling strength margin shall be  $k_y \geq 1,7$ .

**5.6.15** Frames and stiffeners of the fore and stern ends are verified for buckling strength when exposed to forces specified in [5.6.14](#). The longitudinal buckling strength margin of frames and stiffeners shall be not less than  $k_y \geq 2,0$ .

**5.6.16** Deck plates shall be verified for buckling strength when exposed to joint action of the highest stresses due to longitudinal bending (refer to [5.6.1](#) and [5.6.2](#)), and stresses caused by grillages of sides supporting on them. The longitudinal buckling strength margin of deck and top plates shall be not less than  $k_y \geq 1,5$ .

**5.6.17** Deck and top beams shall be verified for buckling strength when exposed to the highest forces transferred from sides supported by them, whereas deck girders – when exposed to stresses due to longitudinal bending. The longitudinal buckling strength margin overall stability safety margin of decks and top framing members shall be not less than  $k_y \geq 1,7$ .

**5.6.18** Buckling strength of transverse bulkheads and fore and stern webs shall be verified when exposed to the highest forces transferred from grillages of sides supported by them and above structures. The longitudinal buckling strength margin shall be not less than  $k_y \geq 2,0$ .

**5.6.19** The longitudinal strength and buckling strength of pillars shall be verified when exposed to the highest forces transferred from the above structures. The longitudinal buckling strength margin shall be not less than  $k_y \geq 2,0$ .

## LONGITUDINAL AND BUCKLING STRENGTH OF HULL STRUCTURAL MEMBERS AND PLATES

(Recommendations on calculation)

### 1 STRESS-STRAIN BEHAVIOR OF FRAMING MEMBERS

**1.1** Stiffness characteristics are determined for the framing members of the section specified in [Fig. 1.1](#). Recommended attached plate of the hull shell (deck plating and bulkhead plating) is generally of a sandwich scheme with a solid or structural orthotropic core with reduced elastic response. The core of the attached plate of sandwich construction under the member is reinforced with a core of the increased density.

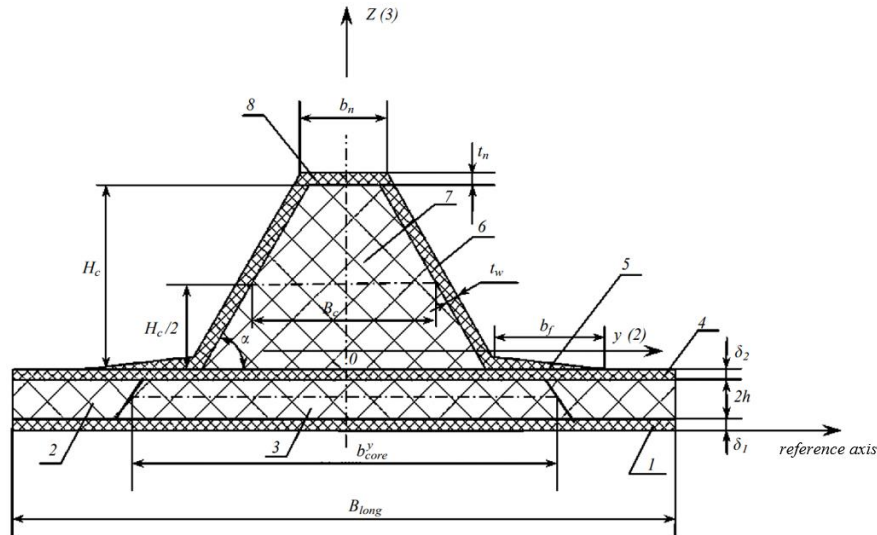


Fig. 1.1

Calculation method for the closed box (trapezoidal) member:

- 1, 4 – load-bearing layers; 2 – core; 3 – reinforcement with a core of increased density; 5 – flange;  
6 – member web; 7 – core of a member; 8 – attached plate

The reduced geometric parameters of the cross-section, such as statical moment and inertia moment, relative to the reference axis shall be determined according to the formulae provided in [Table 1.1](#).

The bending stiffness of the closed box stiffener relative to figure axis  $O_y$  is determined by the following formula:

$$D_{11} = \sum_{i=1}^8 (E_i F_i z_i^2 + i_i) - e^2 \sum_{i=1}^8 E_i F_i$$

where  $e$  = distance between the reference axis and axis  $y$  is determined by the formula

$$e = \frac{\sum_{i=1}^8 E_i F_i z_i}{\sum_{i=1}^8 E_i F_i}$$

$E_i, F_i, z_i$  = [refer to Table 1.1](#).

Table 1.1

**Determination of the reduced geometric parameters of the cross-section**

| i-th element<br>(refer to Fig. A) | Cross-sectional<br>area of the<br>element<br>$F_i$ | Young's<br>modulus<br>of the<br>element<br>$E_i$ | Distance of the<br>element's gravity<br>centre from the<br>reference axis<br>$z_i$ | Reduced<br>cross-sectional<br>area of the element<br>$E_i F_i$ | Reduced statical<br>moment of the<br>element<br>$E_i F_i z_i$                | Reduced inertia moment                                                         |                            |
|-----------------------------------|----------------------------------------------------|--------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------|------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------|
|                                   |                                                    |                                                  |                                                                                    |                                                                |                                                                              | transferred<br>$E_i F_i z_i^2$                                                 | intrinsic<br>$i_i$         |
| 1                                 | $\delta_1 B_{long}$                                | $E_{ll}^{(1)}$                                   | $\delta_1/2$                                                                       | $\delta_1 B_{long} E_{ll}^{(1)}$                               | $\frac{1}{2} \delta_1^2 B_{long} E_{ll}^{(1)}$                               | $\frac{1}{4} \delta_1^3 B_{long} E_{ll}^{(1)}$                                 | —                          |
| 2                                 | $2h(B_{long} - b_{core}^v)$                        | $E_{core}$                                       | $\delta_1 + h$                                                                     | $2h(B_{long} - b_{core}^v) E_{core}$                           | $2h(B_{long} - b_{core}^v) E_{core} (\delta_1 + h)$                          | $2h(B_{long} - b_{core}^v) E_{core} (\delta_1 + h)^2$                          | —                          |
| 3                                 | $2h \cdot b_{core}^y$                              | $E_{core}^y$                                     | $\delta_1 + h$                                                                     | $2h \cdot b_{core}^y E_{core}^y$                               | $2h \cdot b_{core}^y E_{core}^y (\delta_1 + h)$                              | $2h \cdot b_{core}^y E_{core}^y \times (\delta_1 + h)^2$                       | —                          |
| 4                                 | $\delta_2 B_{long}$                                | $E_{ll}^{(2)}$                                   | $\delta_1 + 2h + \delta_2/2$                                                       | $E_{ll}^{(2)} \delta_2 B_{long}$                               | $E_{ll}^{(2)} \delta_2 B_{long} \times (\delta_1 + 2h + \delta_2/2)$         | $E_{ll}^{(2)} \delta_2 B_{long} \times (\delta_1 + 2h + \delta_2/2)^2$         | —                          |
| 5                                 | $t_w b_f$                                          | $E_w$                                            | $\delta_1 + 2h + \delta_2 + t_w/3$                                                 | $E_w t_w b_f$                                                  | $E_w t_w b_f \times (\delta_1 + 2h + \delta_2 + t_w/3)$                      | $E_w t_w b_f \times (\delta_1 + 2h + \delta_2 + t_w/3)^2$                      | —                          |
| 6                                 | $2t_w \frac{H_c}{\sin \alpha}$                     | $E_w$                                            | $\delta_1 + 2h + \delta_2 + H_c/2$                                                 | $2E_w t_w \frac{H_c}{\sin \alpha}$                             | $2E_w t_w \frac{H_c}{\sin \alpha} \times (\delta_1 + 2h + \delta_2 + H_c/2)$ | $2E_w t_w \frac{H_c}{\sin \alpha} \times (\delta_1 + 2h + \delta_2 + H_c/2)^2$ | $\frac{E_w t_w H_c^3}{6}$  |
| 7                                 | $B_c H_c$                                          | $E_c$                                            | $\delta_1 + 2h + \delta_2 + H_c/2$                                                 | $E_c B_c H_c$                                                  | $E_c B_c H_c \times (\delta_1 + 2h + \delta_2 + H_c/2)$                      | $E_c B_c H_c (\delta_1 + 2h + \delta_2 + H_c/2)^2$                             | $\frac{E_c B_c H_c^3}{12}$ |
| 8                                 | $b_n t_n$                                          | $E_n$                                            | $\delta_1 + 2h + \delta_2 + H_c + t_n/2$                                           | $E_n b_n t_n$                                                  | $E_n b_n t_n (\delta_1 + 2h + \delta_2 + H_c + t_n/2)$                       | $E_n b_n t_n (\delta_1 + 2h + \delta_2 + H_c + t_n/2)^2$                       | —                          |
|                                   |                                                    |                                                  |                                                                                    | $\sum_{i=1}^8 E_i F_i$                                         | $\sum_{i=1}^8 E_i F_i z_i$                                                   | $\sum_{i=1}^8 (E_i F_i z_i^2 + i_i)$                                           |                            |

Axial stiffness of the member shall be determined by the formula

$$B_{11} = \sum_{i=1}^8 E_i F_i.$$

The member cross-section shear stiffness is determined by the formula

$$K_{11} = (2G_{13}^w t_w + G^c B_c) H$$

where  $H = H_c + t_n$ .

**1.2** Normal stresses in member elements exposed to the bending moment  $M_1$  and axial force  $T_1$  are determined by the formula

$$\sigma_{11}^{(i)} = E_i \left( \frac{M_1 z_i}{D_{11}} + \frac{T_1}{B_{11}} \right). \quad (1.2)$$

For the most typical elements of the member section, these stresses determined by [Formula \(1.2\)](#) shall be equal to the following:

in the face plate of the member

$$\sigma_{11}^{(8)} = \max \sigma_{11}^{(8)} = E_{11} \left[ \frac{M_1}{D_{11}} (z_8 + t_n/2 - e) + \frac{T_1}{B_{11}} \right];$$

in the section core

$$\sigma_{11}^{(7)} = \max \sigma_{11}^{(7)} = E_c \left[ \frac{M_1}{D_{11}} (z_7 + H_c/2 - e) + \frac{T_1}{B_{11}} \right];$$

in the bottom load-bearing layer of the member attached plate

$$\sigma_{11}^{(1)} = \max \sigma_{11}^{(1)} = E_{hc}^{(1)} \left[ -\frac{M_1 e}{D_{11}} + \frac{T_1}{B_{11}} \right];$$

where  $z_7, z_8$  — [refer to Table 1.1](#).

**1.3** Shear stresses in member elements exposed to the shear force  $N_1$  are determined in two design sections:  
in the middepth of the section

$$z = z^c;$$

at the connection of the member to the attached plate ([refer to Fig. 1.3](#)).

$$z = z^f.$$

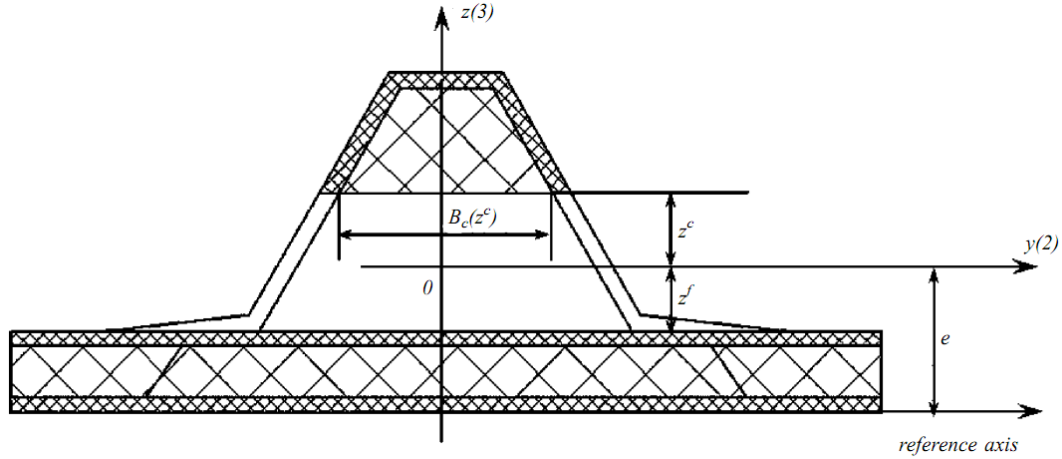


Fig. 1.3  
Calculation method for determination of shear stresses

Shear stresses in section  $z = z^c$  are determined by the following formulae:  
in the core

$$\sigma_{13}^{(c)} = \frac{Q}{2t_w G_{13}^w / G^c + B_c(z^c)};$$

in webs of the member section sheathing

$$\sigma_{13}^{(w)} = \frac{Q}{2t_w G^c / G_{13}^w + B_c(z^c)};$$

where  $G^c$  = shear modulus of the core material;  
 $G_{13}^w$  = shear modulus of the web material in the reinforcement plane;  
 $B_c(z^c) = B_c + 2(z_7 - e - z^c) \frac{\cos \alpha}{\sin \alpha}.$

$$Q = \frac{N_1}{D_{11}} \sum_{j=1}^k E_j \bar{F}_j \bar{z}_j. \quad (1.3)$$

The statical moment of the member cross-section part located above  $z = z^c$  ([refer to Fig. 1.3](#)) shall be determined by the formula

$$\sum_{j=1}^k E_j \bar{F}_j \bar{z}_j = E_n \bar{F}_n \bar{z}_n = E_w \bar{F}_w \bar{z}_w + E_c \bar{F}_c \bar{z}_c$$

where  $\bar{F}_n \bar{z}_n = b_n t_n (z_8 - e);$

$$\bar{F}_w \bar{z}_w = \frac{t_w}{\sin \alpha} [(z_7 + H_c/2 - e)^2 - (z^c)^2];$$

$$\bar{F}_c \bar{z}_c = \frac{1}{2} \left[ B_c + 2 \left( z_4 + \frac{1}{2} \delta_2 - z - e \right) \frac{\cos \alpha}{\sin \alpha} \right] \cdot \left[ \left( z_7 + \frac{1}{2} H_c - e \right)^2 - (z^c)^2 \right].$$

Shear stresses in section  $z = z^f$  ([refer to Fig. 1.3](#)) are determined by the formulas: in the core

$$\sigma_{13}^c = \frac{Q}{2(t_w G_{13}^w / G^c + b_f G_{13}^f / G^c + B_c(z^f))};$$

along the contact line of the load-bearing layer and member flanges

$$\sigma_{13}^f = \frac{Q}{2(t_w + b_f) + B_c(z^f) G^c / G_{13}^f}$$

where  $C_{13}^f$  – interlaminar shear modulus of the flange equal to that of the web material;

$$B_c(z^f) = B_c + H_c \frac{\cos \alpha}{\sin \alpha};$$

$Q$  – determined by [Formula \(1.3\)](#), whereas

$$\sum_{j=1}^k E_j \bar{F}_j \bar{z}_j = E_{ll}^{(1)} \bar{F}_{ll}^{(1)} \bar{z}_{ll}^{(1)} + E_{core} \bar{F}_{core} \bar{z}_{core} + E_{core}^y \bar{F}_{core}^y \bar{z}_{core}^y + E_{ll}^{(2)} \bar{F}_{ll}^{(2)} \bar{z}_{ll}^{(2)};$$

$$E_{ll}^{(1)} \bar{F}_{ll}^{(1)} \bar{z}_{ll}^{(1)} = E_{ll}^{(1)} B_{long} \delta_1 (e - \delta_1/2);$$

$$E_{core} \bar{F}_{core} \bar{z}_{core} = 2E_{core} (B_{long} - b_{core}^y) h (e - z_2);$$

$$E_{core}^y \bar{F}_{core}^y \bar{z}_{core}^y = 2E_{core}^y b_{core}^y h (e - z_3);$$

$$E_{ll}^{(2)} \bar{F}_{ll}^{(2)} \bar{z}_{ll}^{(2)} = E_{ll}^{(2)} B_{long} \delta_2 (e - z_4);$$

**1.4** Member deflections  $w$ , bending moment  $M_1$  and shear force  $N_1$  are determined depending on its conditions of loading and attachment in supporting sections. Formulae to determine the parameters for the most typical cases when calculating FRP hull structures shall be determined based on General engineering approaches to the structural theory of the ship.

## 2 BUCKLING STRENGTH OF FRAMING MEMBERS

**2.1** When the member is exposed to longitudinal (axial) compressive stresses  $T_1$  ( $T_1 < 0$ ), which may lead to its buckling failure, the buckling load is determined by the following formula:

$$T_{1buck} = \frac{T_{1eu}}{1 + T_{1eu}/K_{11}}$$

where  $T_{1eu}$  = theoretical Euler stress;  
 $K_{11}$  = shear stiffness ([refer to 1.3](#)).

**2.2** The theoretical Euler stress of buckling failure is determined by the following formulae:

for freely supported members

$$T_{1eu} = \frac{\pi^2 D_{11}}{l^2};$$

for fixed members

$$T_{1eu} = \frac{4\pi^4 D_{11}}{l^2};$$

for members fixed at one end and hinge-supported at the other

$$T_{1eu} = \frac{2\pi^4 D_{11}}{l^2};$$

where  $D_{11}$  = [refer to 1.1](#);  
 $l$  = member span, distance between member support sections.

### 3 SHEAR STRESS-STRAIN BEHAVIOR OF SINGLE-SKIN PLATES

Shear strain-stress behavior of single-skin plates shall be determined by the following formulae:

$$w = k_1 \frac{pb^4}{E_1 t^3};$$

$$M_1 = k_2 pb^2;$$

$$M_2 = k_3 pb^2;$$

$$M'_2 = k_5 pb^2,$$

where  $p$  = design uniformly distributed load intensity;  
 $M_1$  = bending moment at the plate center in the section parallel to axis  $y$  per unit length of the section;  
 $M_2$  = bending moment at the laminate center in the section parallel to axis  $x$  per unit length of the section;  
 $M'_2$  = bending moment in the middle of the longer side of the supporting contour in the section parallel to axis  $x$  per unit length of the section;  
 $E_1$  and  $E_2$  = Young's moduli of the load-bearing layer in the direction of main reinforcement (direction  $0^\circ$ ) and in the direction  $90^\circ$  to the main reinforcement;  
 $t$  = plate thickness.

Values of factors  $k_i$  for isotropic and orthotropic plates, with the Young's moduli ratio along the shorter and longer sides of the plate equal to 1,0 and 1,5 are specified in Tables [3-1](#) and [3-2](#), for fixed bearing edges, and for plates with freely supported edges.

Where hull or deck platings are made with parallel and diagonal reinforcement schemes  $[(0^\circ/90^\circ)/(+45^\circ/-45^\circ)/(0^\circ/90^\circ)/\dots/(+45^\circ/-45^\circ)/(0^\circ/90^\circ)]$ , plates shall be considered as isotropic ones with average values equal to a half-sum of the relevant characteristics in warp and weft directions of parallel layers:

$$E_{av} = \frac{E_1 + E_2}{2};$$

$$\nu_{av} = \frac{\nu_{12} + \nu_{21}}{2}.$$

where  $\nu_{12}$  and  $\nu_{21}$  = Poisson's ratios of the plate material ([refer to Fig. 3](#)).

The values specified for orthotropic plates refer to FRPs with parallel reinforcement schemes  $[(0^\circ/90^\circ)]$  ( $E_1/E_2 = 1,0$ ;  $E_1/G_{12} = 5$ ) and ( $E_1/E_2 = 1,5$ ;  $E_1/G_{12} = 6$ ), positioned with 1 – ( $0^\circ$ ) direction along the shorter side.

Maximum normal stresses in the plate are determined by the formula

$$\sigma_{ii} = \pm 6M_i/t^2.$$

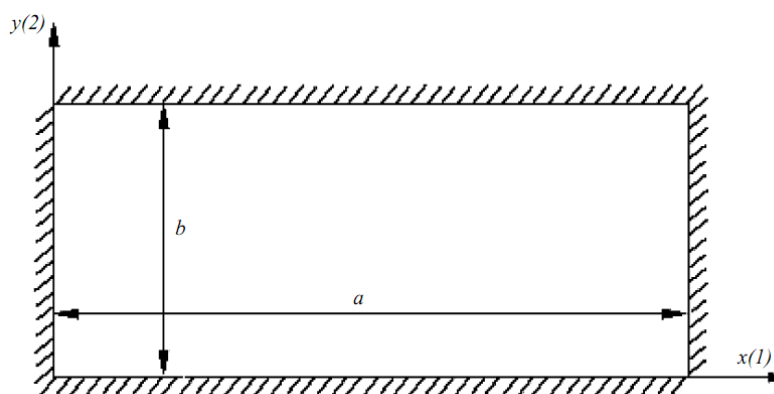


Fig. 3  
Calculation method of single-skin plates

Table 3-1

Values of factors  $k_i$  for plates with fixed edges

| $k_i$ | Plate                        | $a/b$  |        |        |        |        |        |        |          |
|-------|------------------------------|--------|--------|--------|--------|--------|--------|--------|----------|
|       |                              | 1,0    | 1,25   | 1,5    | 1,75   | 2,0    | 2,5    | 3,0    | $\infty$ |
| $k_1$ | Isotropic                    | 0,0138 | 0,02   | 0,0241 | 0,0263 | 0,0276 | 0,0278 | 0,0279 | 0,0284   |
|       | Orthotropic, $E_1/E_2 = 1,0$ | 0,0153 | 0,021  | 0,0255 | 0,0275 | 0,029  | 0,0307 | 0,0312 | 0,032    |
|       | Orthotropic, $E_1/E_2 = 1,5$ | 0,0168 | 0,0227 | 0,0266 | 0,0283 | 0,0299 | 0,0299 | 0,0309 | 0,032    |
| $k_2$ | Isotropic                    | 0,0229 | 0,0228 | 0,0201 | —      | —      | —      | —      | —        |
|       | Orthotropic, $E_1/E_2 = 1,0$ | 0,024  | 0,0235 | 0,021  | —      | —      | —      | —      | —        |
|       | Orthotropic, $E_1/E_2 = 1,5$ | 0,0213 | 0,0196 | 0,0174 | —      | —      | —      | —      | —        |
| $k_3$ | Isotropic                    | 0,0229 | 0,0315 | 0,0368 | 0,0383 | 0,0399 | 0,0404 | 0,0405 | 0,0417   |
|       | Orthotropic, $E_1/E_2 = 1,0$ | 0,024  | 0,033  | 0,0375 | 0,0395 | 0,0408 | 0,0415 | 0,0418 | 0,0425   |
|       | Orthotropic, $E_1/E_2 = 1,5$ | 0,0259 | 0,0344 | 0,0384 | 0,04   | 0,041  | 0,0415 | 0,0419 | 0,0425   |
| $k_5$ | Isotropic                    | 0,0517 | 0,064  | 0,0753 | 0,0814 | 0,0829 | 0,083  | 0,0832 | 0,0833   |
|       | Orthotropic, $E_1/E_2 = 1,0$ | 0,054  | 0,067  | 0,0783 | 0,082  | 0,083  | 0,0833 | 0,0838 | 0,085    |
|       | Orthotropic, $E_1/E_2 = 1,5$ | 0,058  | 0,0698 | 0,0794 | 0,0825 | 0,0832 | 0,0835 | 0,084  | 0,085    |

Table 3-2

Values of factors  $k_i$  for plates with freely supported edges

| $k_i$ | Plate                        | $a/b$  |        |        |        |        |        |        |          |
|-------|------------------------------|--------|--------|--------|--------|--------|--------|--------|----------|
|       |                              | 1,0    | 1,25   | 1,5    | 1,75   | 2,0    | 2,5    | 3,0    | $\infty$ |
| $k_1$ | Isotropic                    | 0,0443 | 0,0656 | 0,0843 | 0,099  | 0,1106 | 0,1221 | 0,1336 | 0,1422   |
|       | Orthotropic, $E_1/E_2 = 1,5$ | 0,0762 | 0,1062 | 0,1225 | 0,1381 | 0,1469 | 0,1542 | 0,1562 | 0,1563   |
| $k_2$ | Isotropic                    | 0,0479 | 0,0503 | 0,05   | 0,0482 | 0,0464 | 0,434  | 0,0404 | 0,0375   |
|       | Orthotropic, $E_1/E_2 = 1,5$ | 0,0493 | 0,0444 | 0,0414 | 0,0292 | 0,0246 | 0,0188 | 0,0134 | 0,0125   |
| $k_3$ | Isotropic                    | 0,0479 | 0,0659 | 0,0812 | 0,0928 | 0,1017 | 0,1101 | 0,1185 | 0,125    |
|       | Orthotropic, $E_1/E_2 = 1,5$ | 0,0661 | 0,0876 | 0,1069 | 0,1135 | 0,1201 | 0,126  | 0,13   | 0,133    |

#### 4 BUCKLING STRENGTH OF SINGLE-SKIN PLATES IN COMPRESSION

**4.1** The buckling strength of freely supported single-skin plates in compression ([Fig. 4.1](#)) shall be determined with account of the aspect ratio of plate sides  $\gamma = a/b$ .

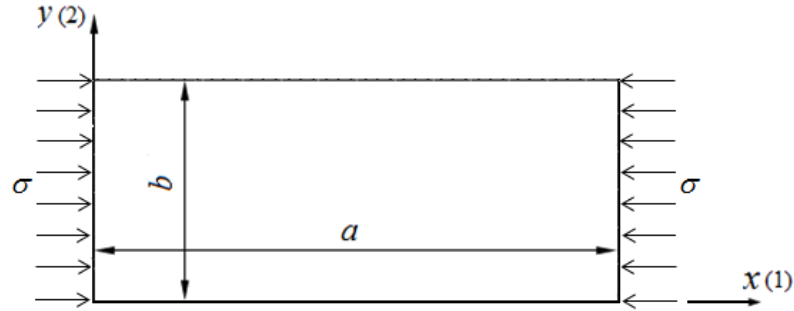


Fig. 4.1  
Calculation method of single-skin plates in compression

**4.2** FRPs with parallel reinforcement scheme  $[(0^\circ/90^\circ)]$ .  
Critical stress is determined by the formula

$$\sigma_{buck} = E_1 B (t/b)^2,$$

where  $E_1$  = Young's compression modulus;  
 $B$  = factor depending on the aspect ratio of plate sides;

$$B = \frac{(m/\gamma)^2 + 2 \left[ v_{21} + 2 \frac{G_{12}}{E_1} (1 - v_{12} v_{21}) \right] + \frac{E_2}{E_1} (\gamma/m)^2}{12(1 - v_{12} v_{21})} \pi^2,$$

where  $\gamma = a/b$  — aspect ratio of plate sides;  
 $m$  = number of half waves at buckling failure;  
 $t$  = plate thickness;  
 $E_1$  and  $E_2$  = Young's moduli in the direction of main reinforcement (direction  $0^\circ$ ) and in the direction  $90^\circ$  to the main reinforcement;  
 $G_{12}$  = shear modulus in the plate plane ([refer to Fig. 4.1](#));  
 $v_{12}$  and  $v_{21}$  = Poisson's ratios of the plate material ([refer to Fig. 4.1](#)).

**4.3** FRPs with parallel and diagonal reinforcement schemes  $[(0^\circ/90^\circ)/(+45^\circ/-45^\circ)/(0^\circ/90^\circ)/\dots/(+45^\circ/-45^\circ)/(0^\circ/90^\circ)]$ .

When determining finite stiffness FRP plates with parallel and diagonal reinforcement scheme, the calculation method for relevant isotropic plates may be used. In such case, the average values of Young's modulus and Poisson's ratio shall be determined by the following formulae:

$$E_{av} = \frac{E_1 + E_2}{2};$$

$$v_{av} = \frac{v_{12} + v_{21}}{2}.$$

Critical stress is determined by the formula

$$\sigma_{buck} = E_{av} B (t/b)^2.$$

Values of factor  $B$  for  $0,4 \leq \gamma \leq 3,0$  are specified in [Table 4.3](#) and in [Figs. 4.3-1 — 4.3-3](#).

Table 4.3

Values of factor  $B$  depending on the aspect ratio of plate sides

| $E_1$ ,<br>GPa | $m$                           | 1    | 1    | 1    | 1    | 1    | 1    | 2    | 2    | 2    | 2    | 2    | 3    | 3    | 3    |
|----------------|-------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|                | $\gamma$<br>$G_{12}$ ,<br>GPa | 0,4  | 0,6  | 0,8  | 1    | 1,2  | 1,4  | 1,6  | 1,8  | 2    | 2,2  | 2,4  | 2,6  | 2,8  | 3    |
| 15             | 5                             | 6,57 | 3,99 | 3,44 | 3,57 | 4,06 | 4,78 | 3,44 | 3,45 | 3,57 | 3,78 | 4,06 | 3,43 | 3,48 | 3,57 |
|                | 8,5                           | 6,96 | 4,38 | 3,82 | 3,96 | 4,44 | 5,16 | 3,82 | 3,83 | 3,96 | 4,16 | 4,44 | 3,82 | 3,86 | 3,96 |
|                | 12                            | 7,34 | 4,76 | 4,21 | 4,34 | 4,82 | 5,54 | 4,21 | 4,22 | 4,34 | 4,55 | 4,82 | 4,20 | 4,25 | 4,34 |
| 20             | 5                             | 6,44 | 3,86 | 3,30 | 3,44 | 3,92 | 4,64 | 3,30 | 3,31 | 3,44 | 3,64 | 3,92 | 3,30 | 3,34 | 3,44 |
|                | 8,5                           | 6,73 | 4,14 | 3,59 | 3,72 | 4,21 | 4,93 | 3,59 | 3,60 | 3,72 | 3,93 | 4,21 | 3,58 | 3,63 | 3,72 |
|                | 12                            | 7,01 | 4,43 | 3,88 | 4,01 | 4,49 | 5,21 | 3,88 | 3,89 | 4,01 | 4,22 | 4,49 | 3,87 | 3,92 | 4,01 |
| 25             | 5                             | 6,36 | 3,77 | 3,22 | 3,35 | 3,84 | 4,56 | 3,22 | 3,23 | 3,35 | 3,56 | 3,84 | 3,21 | 3,26 | 3,35 |
|                | 8,5                           | 6,59 | 4,00 | 3,45 | 3,58 | 4,07 | 4,79 | 3,45 | 3,46 | 3,58 | 3,79 | 4,07 | 3,44 | 3,49 | 3,58 |
|                | 12                            | 6,82 | 4,23 | 3,68 | 3,81 | 4,30 | 5,02 | 3,68 | 3,69 | 3,81 | 4,02 | 4,30 | 3,67 | 3,72 | 3,81 |
| 30             | 5                             | 6,30 | 3,72 | 3,17 | 3,30 | 3,78 | 4,50 | 3,17 | 3,18 | 3,30 | 3,51 | 3,78 | 3,16 | 3,21 | 3,30 |
|                | 8,5                           | 6,49 | 3,91 | 3,36 | 3,49 | 3,97 | 4,69 | 3,36 | 3,37 | 3,49 | 3,70 | 3,97 | 3,35 | 3,40 | 3,49 |
|                | 12                            | 6,68 | 4,10 | 3,55 | 3,68 | 4,17 | 4,89 | 3,55 | 3,56 | 3,68 | 3,89 | 4,17 | 3,54 | 3,59 | 3,68 |
| 35             | 5                             | 6,26 | 3,68 | 3,13 | 3,26 | 3,74 | 4,46 | 3,13 | 3,14 | 3,26 | 3,47 | 3,74 | 3,12 | 3,17 | 3,26 |
|                | 8,5                           | 6,43 | 3,84 | 3,29 | 3,43 | 3,91 | 4,63 | 3,29 | 3,30 | 3,43 | 3,63 | 3,91 | 3,29 | 3,33 | 3,43 |
|                | 12                            | 6,59 | 4,01 | 3,46 | 3,59 | 4,07 | 4,79 | 3,46 | 3,47 | 3,59 | 3,80 | 4,07 | 3,45 | 3,50 | 3,59 |
| 40             | 5                             | 6,23 | 3,65 | 3,10 | 3,23 | 3,71 | 4,43 | 3,10 | 3,11 | 3,23 | 3,44 | 3,71 | 3,09 | 3,14 | 3,23 |
|                | 8,5                           | 6,38 | 3,79 | 3,24 | 3,38 | 3,86 | 4,58 | 3,24 | 3,25 | 3,38 | 3,58 | 3,86 | 3,24 | 3,28 | 3,38 |
|                | 12                            | 6,52 | 3,94 | 3,39 | 3,52 | 4,00 | 4,72 | 3,39 | 3,40 | 3,52 | 3,73 | 4,00 | 3,38 | 3,43 | 3,52 |
| 50             | 5                             | 6,19 | 3,61 | 3,06 | 3,19 | 3,67 | 4,39 | 3,06 | 3,07 | 3,19 | 3,40 | 3,67 | 3,05 | 3,10 | 3,19 |
|                | 8,5                           | 6,31 | 3,72 | 3,17 | 3,31 | 3,79 | 4,51 | 3,17 | 3,18 | 3,31 | 3,51 | 3,79 | 3,17 | 3,21 | 3,31 |
|                | 12                            | 6,42 | 3,84 | 3,29 | 3,42 | 3,90 | 4,62 | 3,29 | 3,30 | 3,42 | 3,63 | 3,90 | 3,28 | 3,33 | 3,42 |
| 60             | 5                             | 6,16 | 3,58 | 3,03 | 3,16 | 3,65 | 4,37 | 3,03 | 3,04 | 3,16 | 3,37 | 3,65 | 3,02 | 3,07 | 3,16 |
|                | 8,5                           | 6,26 | 3,68 | 3,13 | 3,26 | 3,74 | 4,46 | 3,13 | 3,14 | 3,26 | 3,47 | 3,74 | 3,12 | 3,17 | 3,26 |
|                | 12                            | 6,36 | 3,77 | 3,22 | 3,35 | 3,84 | 4,56 | 3,22 | 3,23 | 3,35 | 3,56 | 3,84 | 3,21 | 3,26 | 3,35 |

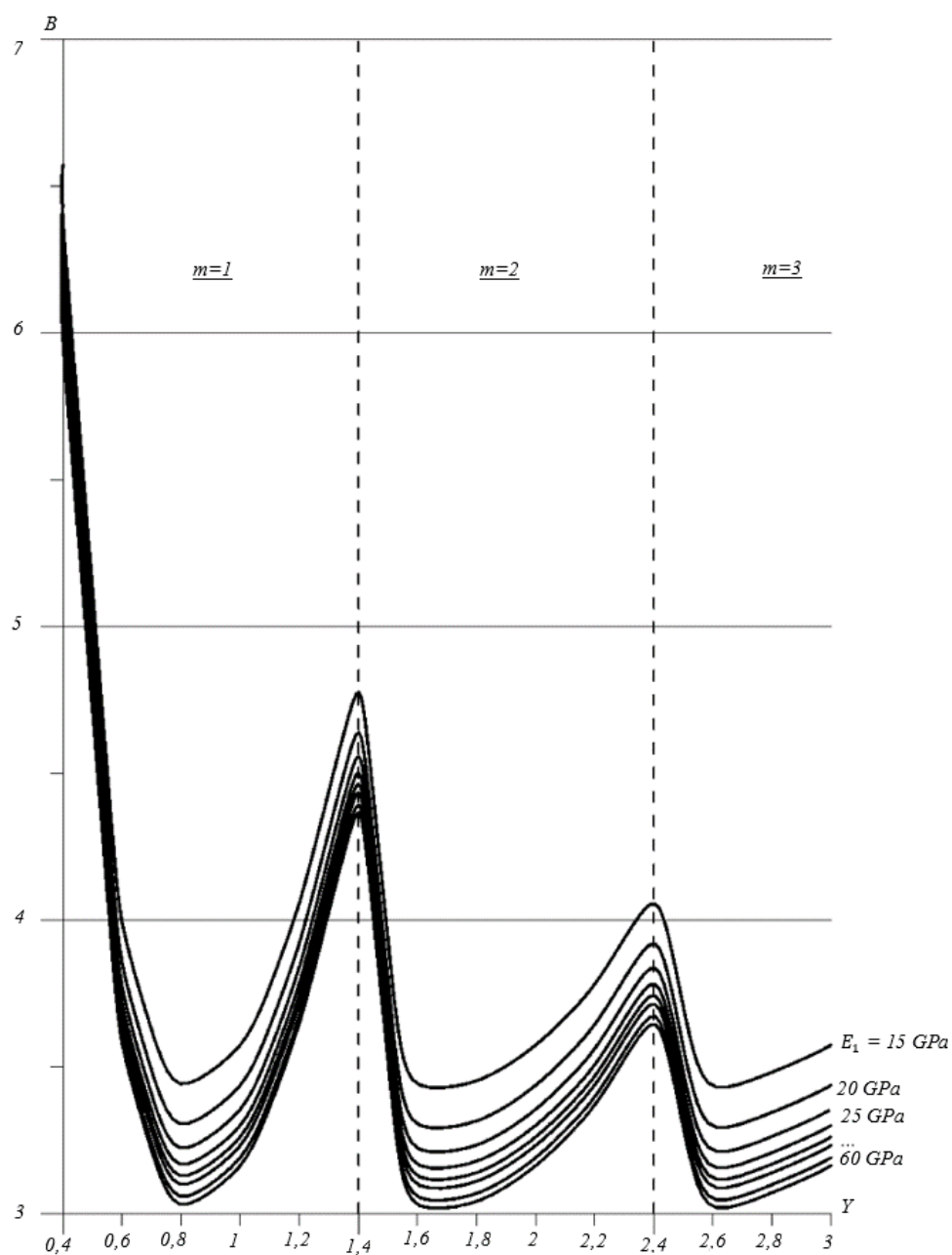


Fig. 4.3-1  
Values of factor  $B$  at  $G_{12} = 5$  GPa

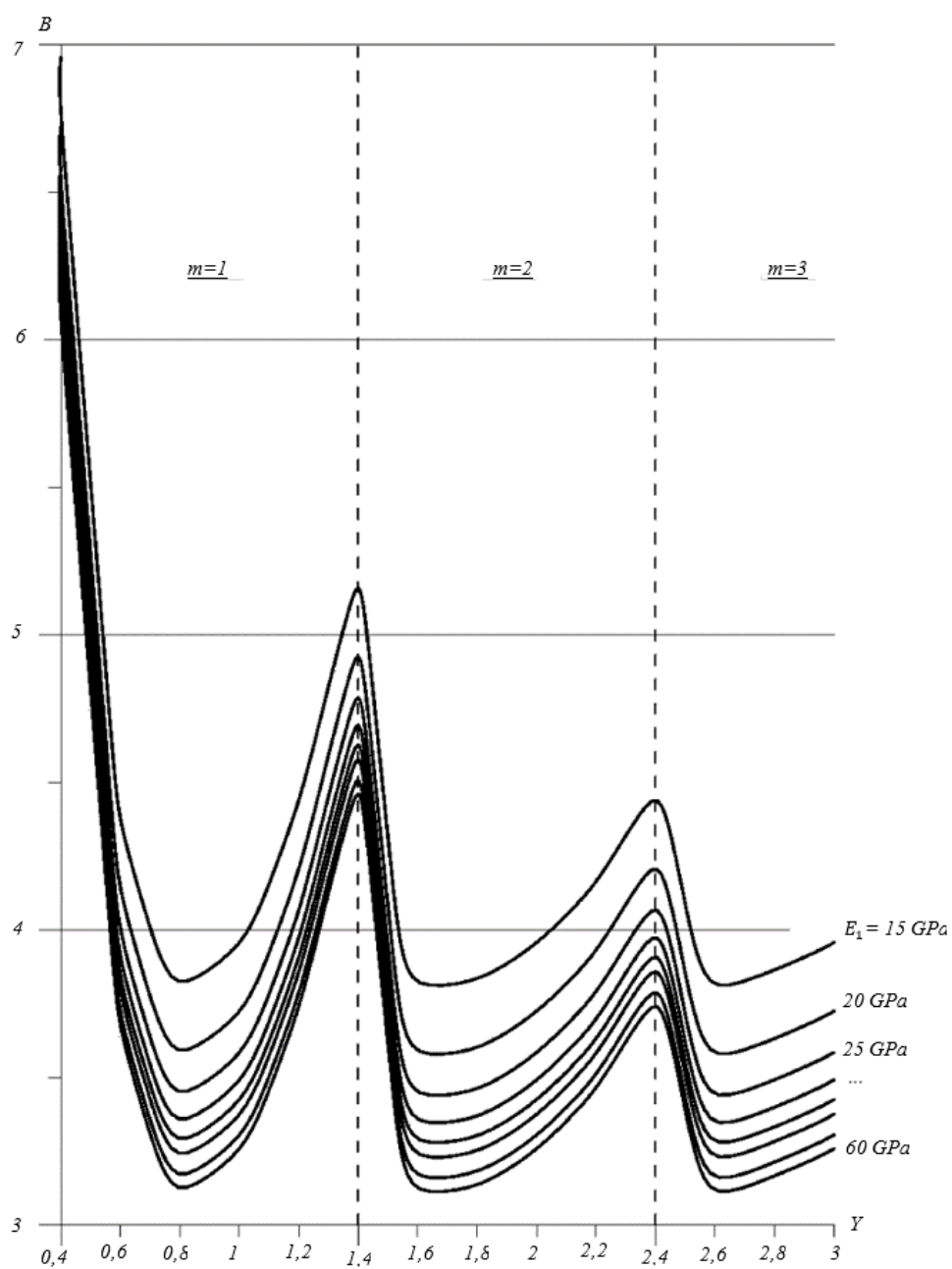


Fig. 4.3-2  
Values of factor  $B$  at  $G_{12} = 8,5$  GPa

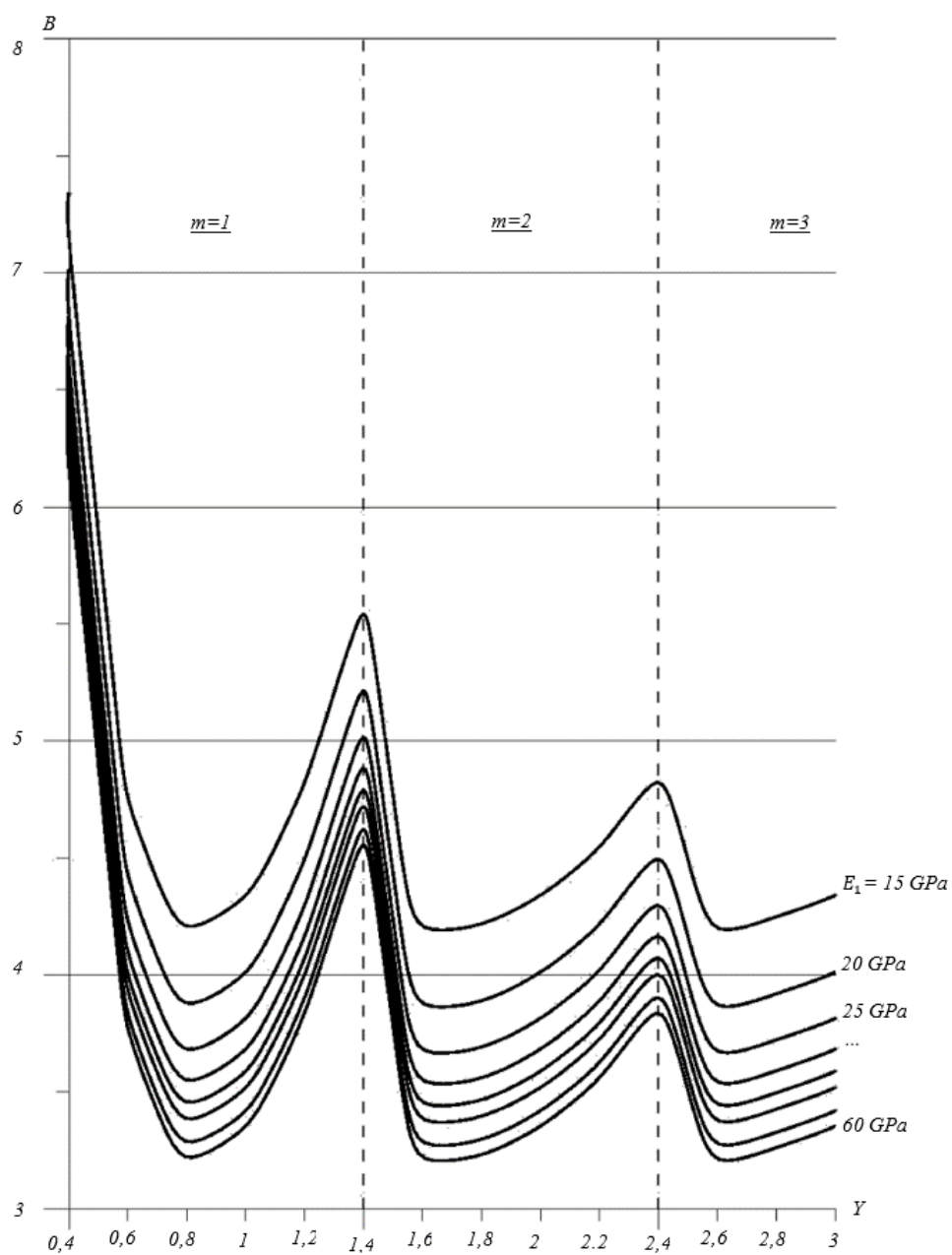


Fig. 4.3-3  
Values of factor  $B$  at  $G_{12} = 12$  GPa

## 5 SHEAR BUCKLING STRENGTH OF SINGLE-SKIN PLATES

**5.1** The buckling strength of freely supported single-skin plates ([Fig. 5.1](#)) for shear stress of FRPs with parallel reinforcement scheme [(0°/90°)] shall be determined with account of the aspect ratio of plate sides  $\gamma = a/b$ .

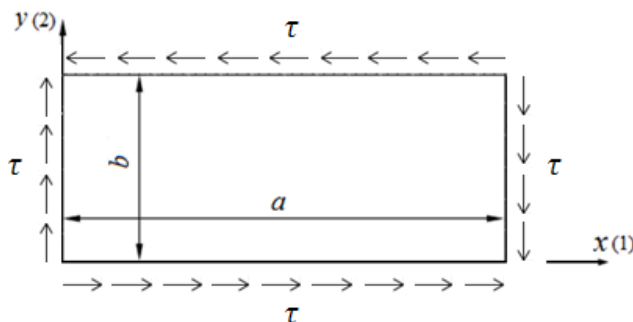


Fig. 5.1  
Calculation method of single-skin plates under shear

**5.2** At  $\gamma \geq 1$  the shear critical stress is determined by the formula

$$\tau_{buck} = (E_1/\gamma^4 + 2E_3/\gamma^4 + E_2)B(t/b)^2,$$

where  $E_3 = E_1 v_{21} + 2(1 - v_{12} v_{21}) G_{12}$ ;

$$B = \frac{\pi^4 \gamma}{384(1 - v_{12} v_{21})} \sqrt{\frac{100}{1,395 + 4(k_1 + k_2)}};$$

where  $k_1 = \frac{1+2\gamma^2 A + \gamma^4 \xi}{81+18\gamma^2 A + \gamma^4 \xi}$ ;  $k_2 = \frac{1+2\gamma^2 A + \gamma^4 \xi}{1+18\gamma^2 A + 81\gamma^4 \xi}$ ;  
 $A = v_{21} + 2 \frac{G_{12}}{E_1} (1 - v_{12} v_{21})$ ;  $\gamma = a/b$ ;  $\xi = \frac{E_2}{E_1}$ ;  
 $E_1, E_2, G_{12}, v_{12}$  and  $v_{21}$  — [refer to 4](#).

Note. Reinforcement direction (0°) — along side of length  $a$  ([refer to Fig. 5.1](#)).

Values of factor  $B$  for  $\gamma \geq 1$  are specified in [Table 5.2](#) and in [Fig. 5.2](#).

Table 5.2

Values of factor  $B$  depending on the aspect ratio of plate sides at  $\gamma \geq 1$

| $E_1$ ,<br>GPa | $G_{12}$ , GPa \ $\gamma$ | 1    | 1,2  | 1,4  | 1,6  | 1,8  | 2    | 2,2  | 2,4  | 2,6  | 2,8  | 3    |
|----------------|---------------------------|------|------|------|------|------|------|------|------|------|------|------|
| 15             | 5                         | 1,99 | 2,39 | 2,79 | 3,18 | 3,58 | 3,98 | 4,38 | 4,78 | 5,17 | 5,57 | 5,97 |
|                | 8,5                       | 1,96 | 2,36 | 2,75 | 3,14 | 3,53 | 3,93 | 4,32 | 4,71 | 5,10 | 5,50 | 5,89 |
|                | 12                        | 1,94 | 2,33 | 2,72 | 3,11 | 3,49 | 3,88 | 4,27 | 4,66 | 5,05 | 5,44 | 5,82 |
| 20             | 5                         | 2,00 | 2,40 | 2,80 | 3,20 | 3,60 | 4,00 | 4,40 | 4,80 | 5,20 | 5,60 | 6,00 |
|                | 8,5                       | 1,98 | 2,37 | 2,77 | 3,17 | 3,56 | 3,96 | 4,35 | 4,75 | 5,14 | 5,54 | 5,94 |
|                | 12                        | 1,96 | 2,35 | 2,74 | 3,14 | 3,53 | 3,92 | 4,31 | 4,70 | 5,10 | 5,49 | 5,88 |
| 25             | 5                         | 2,01 | 2,41 | 2,81 | 3,21 | 3,61 | 4,02 | 4,42 | 4,82 | 5,22 | 5,62 | 6,02 |
|                | 8,5                       | 1,99 | 2,39 | 2,78 | 3,18 | 3,58 | 3,98 | 4,38 | 4,77 | 5,17 | 5,57 | 5,97 |
|                | 12                        | 1,97 | 2,37 | 2,76 | 3,16 | 3,55 | 3,94 | 4,34 | 4,73 | 5,13 | 5,52 | 5,92 |
| 30             | 5                         | 2,01 | 2,42 | 2,82 | 3,22 | 3,62 | 4,03 | 4,43 | 4,83 | 5,23 | 5,64 | 6,04 |
|                | 8,5                       | 2,00 | 2,40 | 2,79 | 3,19 | 3,59 | 3,99 | 4,39 | 4,79 | 5,19 | 5,59 | 5,99 |
|                | 12                        | 1,98 | 2,38 | 2,77 | 3,17 | 3,57 | 3,96 | 4,36 | 4,76 | 5,15 | 5,55 | 5,95 |
| 35             | 5                         | 2,02 | 2,42 | 2,82 | 3,23 | 3,63 | 4,03 | 4,44 | 4,84 | 5,24 | 5,65 | 6,05 |
|                | 8,5                       | 2,00 | 2,40 | 2,80 | 3,20 | 3,60 | 4,00 | 4,40 | 4,80 | 5,20 | 5,61 | 6,01 |
|                | 12                        | 1,99 | 2,39 | 2,78 | 3,18 | 3,58 | 3,98 | 4,38 | 4,77 | 5,17 | 5,57 | 5,97 |

| $E_1$ , GPa | $\gamma$ | 1    | 1,2  | 1,4  | 1,6  | 1,8  | 2    | 2,2  | 2,4  | 2,6  | 2,8  | 3    |
|-------------|----------|------|------|------|------|------|------|------|------|------|------|------|
| 40          | 5        | 2,02 | 2,42 | 2,83 | 3,23 | 3,63 | 4,04 | 4,44 | 4,85 | 5,25 | 5,65 | 6,06 |
|             | 8,5      | 2,01 | 2,41 | 2,81 | 3,21 | 3,61 | 4,01 | 4,41 | 4,81 | 5,22 | 5,62 | 6,02 |
|             | 12       | 1,99 | 2,39 | 2,79 | 3,19 | 3,59 | 3,99 | 4,39 | 4,79 | 5,18 | 5,58 | 5,98 |
| 50          | 5        | 2,02 | 2,43 | 2,83 | 3,24 | 3,64 | 4,05 | 4,45 | 4,85 | 5,26 | 5,66 | 6,07 |
|             | 8,5      | 2,01 | 2,41 | 2,82 | 3,22 | 3,62 | 4,02 | 4,43 | 4,83 | 5,23 | 5,63 | 6,04 |
|             | 12       | 2,00 | 2,40 | 2,80 | 3,20 | 3,60 | 4,00 | 4,40 | 4,81 | 5,21 | 5,61 | 6,01 |
| 60          | 5        | 2,03 | 2,43 | 2,84 | 3,24 | 3,65 | 4,05 | 4,46 | 4,86 | 5,27 | 5,67 | 6,08 |
|             | 8,5      | 2,02 | 2,42 | 2,82 | 3,23 | 3,63 | 4,03 | 4,44 | 4,84 | 5,24 | 5,65 | 6,05 |
|             | 12       | 2,01 | 2,41 | 2,81 | 3,21 | 3,61 | 4,02 | 4,42 | 4,82 | 5,22 | 5,62 | 6,02 |

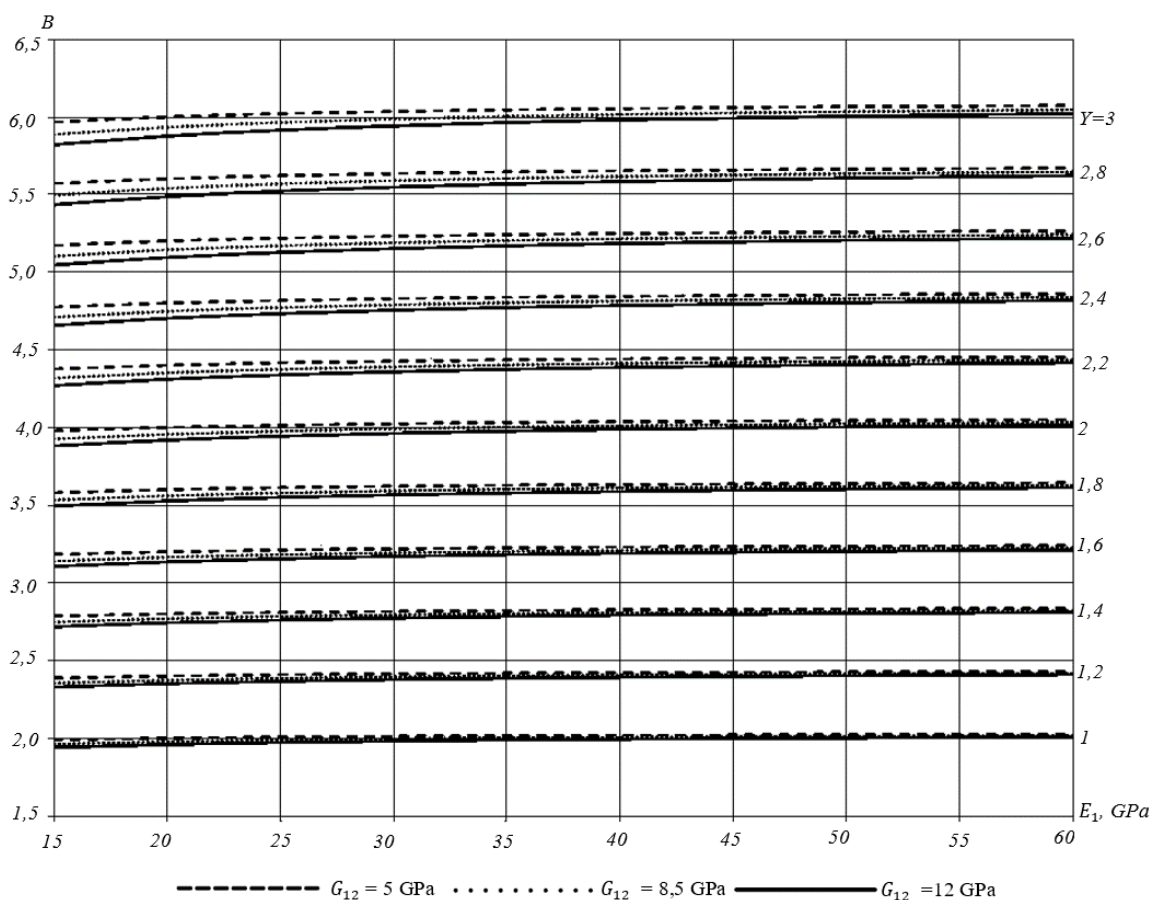


Fig. 5.2

 Values of factor  $B$  depending on the aspect ratio of plate sides at  $\gamma \geq 1$ 

**5.3** At  $\gamma = 0,5$  the shear critical stress is determined by the formula

$$\tau_{buck} = B(t/b)^2,$$

$$\text{where } B = 0,00952 \frac{\pi^4}{1-\nu_{12}\nu_{21}} \sqrt{D - \sqrt{D^2 - 9,58C}};$$

$$\begin{aligned} \text{where } C &= E' \bar{E} \cdot \hat{E} \cdot \bar{E}; \\ D &= 4,82E' \bar{E} + 1,31E' \bar{E} + 0,64\hat{E} \cdot \bar{E} + 0,101\bar{E} \cdot \bar{E}; \\ E' &= E_1 + 2E_3 + E_2; \\ \bar{E} &= 16E_1 + 18E_3 + 5,06E_2; \end{aligned}$$

$$\hat{E} = E_1 + 8E_3 + 16E_2;$$

$$\tilde{E} = 16E_1 + 50E_3 + 39E_2.$$

Values of factor  $B$  for  $\gamma = 0,5$  are specified in [Table 5.3](#) and in [Fig. 5.3](#).

Table 5.3

Values of factor  $B$  depending on the aspect ratio of plate sides at  $\gamma = 0,5$

| $G_{12} \backslash E_1$ | 15     | 20     | 25     | 30     | 35     | 40     | 50      | 60      |
|-------------------------|--------|--------|--------|--------|--------|--------|---------|---------|
| 5                       | 347,76 | 426,46 | 505,05 | 583,58 | 662,07 | 740,54 | 897,41  | 1054,25 |
| 8,5                     | 425,38 | 504,45 | 583,32 | 662,06 | 740,71 | 819,31 | 976,39  | 1133,37 |
| 12                      | 502,45 | 581,89 | 661,05 | 740,02 | 818,87 | 897,63 | 1054,96 | 1212,13 |

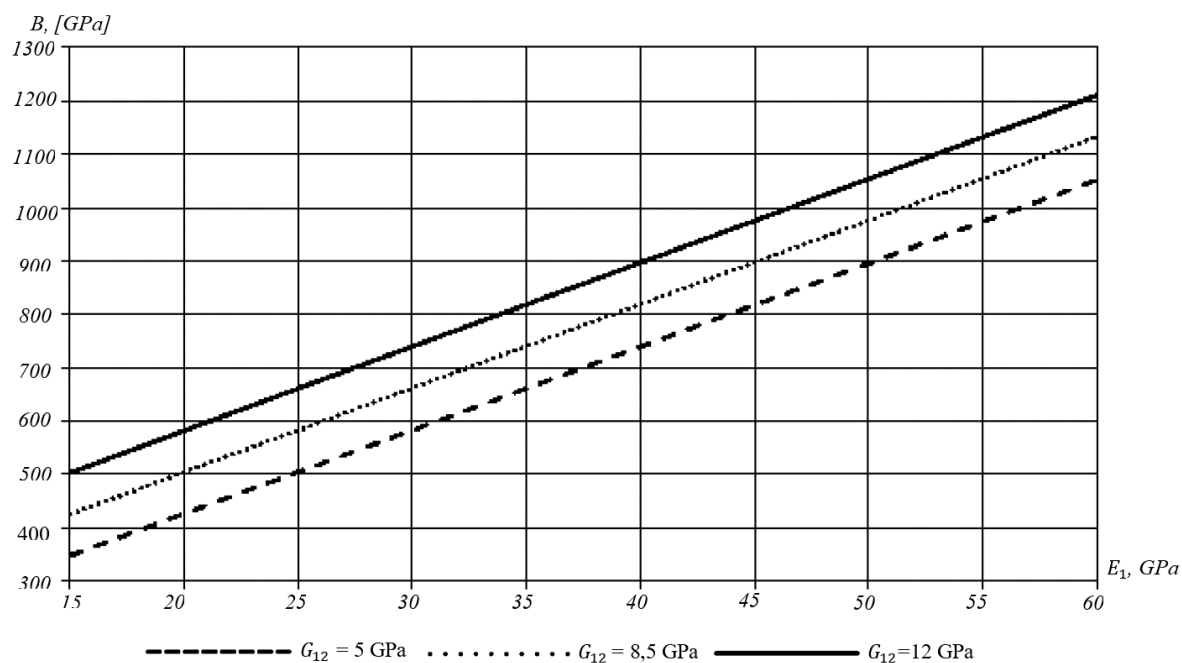


Fig. 5.3

Values of factor  $B$ , in GPa, depending on the aspect ratio of plate sides at  $\gamma = 0,5$

## 6 STRESS-STRAIN BEHAVIOR OF SANDWICH PLATES AT CYLINDRICAL BENDING

This Section contains the formulae to determine maximum deflections, maximum normal stresses in load-bearing layers and maximum shear stresses in the core for sandwich plates with isotropic core of the FRP hull structures.

Transverse deflection of cylindrical plate bending taking into account various modes of plate edge attachment ([Fig. 6](#)) where  $\gamma = a/b > 3$  is considered. In all cases, the load shall be perpendicular to the plate plane.

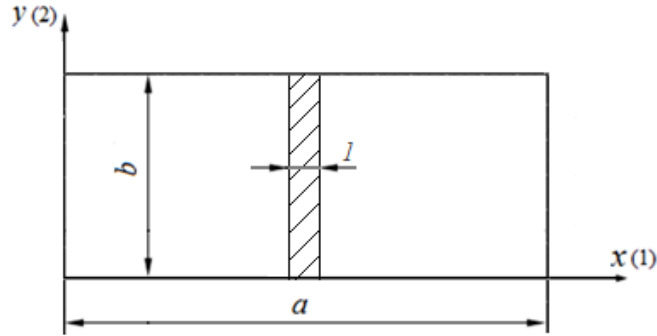


Fig. 6  
Cylindrical bending of sandwich plates

### Symbols.

For the purpose of this Section, the following symbols have been adopted:

$\delta$  = thickness of each load-bearing layer, in m;

$h$  = half thickness of the sandwich plate core, in m;

$E_{ll}$  = Young's modulus of load-bearing layers made of isotropic material, in Pa;

$G_{ll}$  = shear modulus in plane of load-bearing layers, in Pa;

$\mu_{ll}$  = Poisson's ratio of load-bearing layers;

$E_{core}$  = Young's modulus of the isotropic core, in Pa;

$G_{core}$  = shear modulus of the isotropic core, in Pa;

$\mu_{core}$  = Poisson's ratio of the isotropic core;

$q$  = uniformly distributed transverse load per surface area, in N/m<sup>2</sup>;

$p$  = uniformly distributed transverse load per unit length, in N/m;

$W$  = maximum deflection of load-bearing layers of the plate, in m;

$\sigma_x$  = maximum normal stresses in load-bearing layers, in Pa;

$\tau_{xz}$  = maximum shear stresses in the isotropic core, in Pa.

Where load-bearing layers are made of the same isotropic material and have the same thickness, the following conditions shall be met:

$$E_i^1 = E_i^2 = E_{ll}, \quad \mu_{ij}^1 = \mu_{ij}^2 = \mu_{ll}, \quad \delta_1 = \delta_2 = \delta,$$

where  $i, j = 1, 2, 3$  — directions of coordinate axes;

$E_i^1, E_i^2$  = Young's moduli of load-bearing layers;

$\mu_{ij}^1, \mu_{ij}^2$  = Poisson's ratios of load-bearing layers;

$\delta_1, \delta_2$  = thicknesses of load-bearing layers.

For the core made of isotropic material, the following conditions shall be met:

$$E_i^{core} = E_{core}, \mu_{ij} = \mu_{core},$$

where  $E_i^{core}$  = Young's modulus of the core;  
 $\mu_{ij}$  = Poisson's ratio of the core.

The formulae specified in this Section may be used where the following conditions are met:

$$2,0 \cdot 10^{-4} \leq \frac{G_{core}}{\bar{E}} \leq 2,0 \cdot 10^{-2}, \quad 0,1 \leq \delta/h \leq 0,25,$$

where  $\bar{E} = \frac{E_{ll}}{(1 - \mu_{ll}^2)}$ .

The formulae may be used for calculation of sandwich plates with orthotropic load-bearing layers, where their Young's moduli do not vary more than 20 % (relative to the highest value of the moduli), i.e. if the following condition is met:

$$(1 - \frac{E_2}{E_1}) \cdot 100 < 20 \% \text{ at } E_1 > E_2,$$

where  $E_1$  and  $E_2$  = Young's moduli of the load-bearing layer in the direction of main reinforcement (direction  $0^\circ$ ) and in the direction  $90^\circ$  to the main reinforcement.

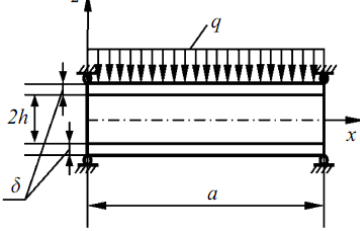
In this case, the arithmetic mean shall be taken as the Young's modulus for calculations. The values used in the formulae specified in [Table 6](#) are determined by the following formulae:

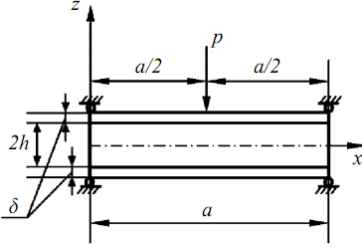
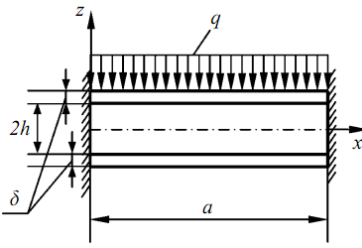
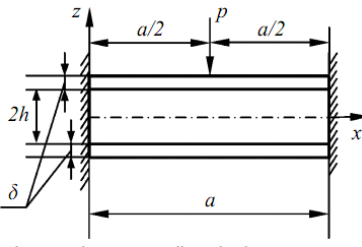
$$B_{ll} = \frac{E_{ll}\delta}{1 - \mu_{ll}^2}, \quad B_{core} = \frac{2E_{core}h}{1 - \mu_{core}^2}, \quad D_{ll} = \frac{E_{ll}\delta^3}{12(1 - \mu_{ll}^2)}, \quad D_{core} = B_{core} \frac{h^2}{3},$$

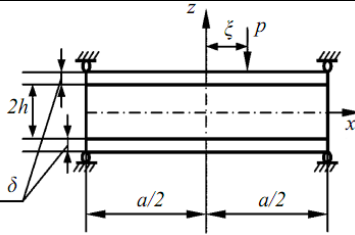
$$k = \frac{\pi^2 B_{ll} h_{long}}{G_{core} a^2}, \quad \gamma = \frac{\pi}{a} \sqrt{1 / \left( k \frac{2D_{ll}\eta}{D_{pl}} \right)}, \quad h_{long} = h \left( 1 + \frac{D_{core}}{2B_{ll}h^2} \right),$$

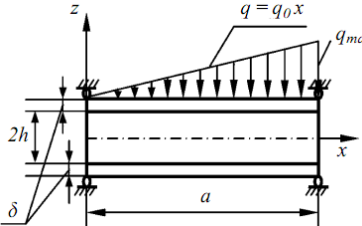
$$\eta = 1 + \frac{D_{core}\delta^2}{8h_{long}hD_{ll}}, \quad D_{pl} = 2(D_{ll} + B_{ll}(h + \delta/2)^2) + D_{core}, \quad \bar{E} = \frac{E_{ll}}{1 - \mu_{ll}^2}.$$

Table 6

| Type of load                                                                                                                                                              | Stresses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Deflections                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p>Plate edges are freely supported, the transverse load is uniformly distributed</p> | <p>Normal stresses in load-bearing layers are maximum at <math>x = a/2</math>; <math>z = \pm(h + \delta)</math>:</p> $ \sigma_x  = \left  \frac{qa^2}{8D_{pl}} \cdot \frac{B_{ll}(h + \delta)}{\delta} m_2 \right ,$ <p>shear stresses in the core are maximum at <math>x = 0, a</math>; <math>z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{qa}{4(h_{long} + \delta/2)} \cdot \frac{h_{long}}{h} m_3 \right $ <p>where <math>m_2 = 1 - \frac{4k}{\pi^2} \left( \frac{\delta}{h_{long}} + \frac{4D_{ll}\eta}{D_{pl}} - \frac{2 + \delta/h_{long}}{1 + \delta/h} \times \left( \frac{\delta}{h} + \left[ \frac{2D_{ll}}{D_{pl}} \left( 1 - \frac{D_{core}\delta}{4hD_{ll}} \right) - \frac{\delta}{h(2 + \delta/h_{long})} \right] \left( 1 - \frac{2D_{ll}\eta}{D_{pl}} \right) \right) \text{sch} \left( \frac{\gamma a}{2} \right) \right)</math>,<br/> <math>m_3 = \left( 1 - \frac{2D_{ll}\eta}{D_{pl}} \right) \left( 1 - \frac{4k}{\pi^2} \cdot \frac{2 \cdot D_{ll} \cdot \eta}{D_{pl}} \cdot \frac{\gamma \cdot a}{2} \cdot \text{th} \left( \frac{\gamma \cdot a}{2} \right) \right)</math>.</p> | <p>Plate deflection is maximum in the section at <math>x = a/2</math>:</p> $ W  = \left  \frac{5}{384} \cdot \frac{qa^4}{D_{pl}} m_1 \right $ <p>where <math>m_1 = 1 + \frac{48k}{5\pi^2} \left( 1 - \frac{2D_{ll}\eta}{D_{pl}} \right) \times \left( 1 - \frac{8k}{\pi^2} \cdot \frac{2D_{ll}\eta}{D_{pl}} \left( 1 - \text{sch} \left( \frac{\gamma a}{2} \right) \right) \right)</math>.</p> |

| Type of load                                                                                                                                                                                  | Stresses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Deflections                                                                                                                                                                                                                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p>Plate edges are freely supported, the transverse load is uniformly distributed in the center section</p> | <p>Normal stresses in load-bearing layers are maximum at <math>x = a/2</math>; <math>z = \pm(h + \delta)</math>:</p> $ \sigma_x  = \left  \frac{pa}{4} \cdot \frac{B_{ll}(h + \delta)}{\delta D_{pl}} m_2 \right ,$ <p>shear stresses in the core are maximum at <math>0 \leq x \leq a</math>; <math>z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{p}{4(h_{long} + \delta/2)} \cdot \frac{h_{long}}{h} m_3 \right $ <p>where <math>m_2 = 1 - \frac{1}{(1 + \delta/h)\eta} \cdot \frac{2th(\gamma a/2)}{\gamma a} \times \left( \left(1 + \frac{\delta}{2h_{long}}\right) \left(1 - \frac{D_{core}\delta}{4hD_{ll}}\right) + \frac{\delta}{2h} \left(\eta - \frac{D_{pl}}{2D_{ll}}\right) \right)</math>,<br/> <math>m_3 = \left(1 - \frac{2D_{ll}\eta}{D_{pl}}\right) \left(1 - sch\left(\frac{\gamma a}{2}\right)\right)</math>.</p>  | <p>Plate deflection is maximum in the section at <math>x = a/2</math>:</p> $ W  = \left  \frac{pa^3}{48D_{pl}} m_1 \right $ <p>where <math>m_1 = 1 + \frac{12k}{\pi^2} \left(1 - \frac{2D_{ll}\eta}{D_{pl}}\right) \times \left(1 - \frac{2th(\gamma a/2)}{\gamma a}\right)</math>.</p>                        |
|  <p>Plate edges are fixed, the transverse load is uniformly distributed</p>                                 | <p>Normal stresses in load-bearing layers are maximum at <math>x = 0, a</math>; <math>z = \pm(h + \delta)</math>:</p> $ \sigma_x  = \left  \frac{\bar{E}qa^2}{12D_{pl}} (h + \delta) \right ,$ <p>shear stresses in the core are maximum at <math>x = 0, a</math>; <math>z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{\bar{D}}{4hD_{pl}} qa \right ,$ <p>where <math>\bar{D} = 2B_{ll}h(h + \delta/2) + D_{core}</math>.</p>                                                                                                                                                                                                                                                                                                                                                                                                          | <p>Plate deflection is maximum in the section at <math>x = a/2</math>:</p> $ W  = \left  \frac{1}{384} \cdot \frac{qa^4}{D_{pl}} m_1 \right ,$ <p>where <math>m_1 = 1 + \frac{48k_1}{\pi^2}</math>,<br/> <math>k_1 = \frac{\pi^2 B_0 h}{2G_{core} a^2}</math><br/> <math>B_0 = 2B_{ll} + B_{core}/3</math></p> |
|  <p>Plate edges are fixed, the transverse load is uniformly distributed in the center section</p>          | <p>Normal stresses in load-bearing layers are maximum at <math>x = a/2</math>; <math>z = \pm(h + \delta)</math>:</p> $ \sigma_x  = \left  \frac{pa}{8} \cdot \frac{B_{ll}(h + \delta)}{\delta D_{pl}} m_2 \right ,$ <p>shear stresses in the core are maximum at <math>0 \leq x \leq a</math>; <math>z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{p}{4(h_{long} + \delta/2)} \cdot \frac{h_{long}}{h} m_3 \right ,$ <p>where <math>m_2 = 1 - \frac{th(\gamma a/4)}{\eta(1 + \delta/h)(\gamma a/4)} \times \left( \left(1 + \frac{D_{core}\delta}{4hD_{ll}}\right) \left(1 + \frac{\delta}{2h_{long}}\right) - \frac{\delta D_{pl}}{4hD_{ll}} \left(1 - \frac{2D_{ll}\eta}{D_{pl}}\right) \right)</math>,<br/> <math>m_3 = \left(1 - \frac{2D_{ll}\eta}{D_{pl}}\right) \left(1 - sch\left(\frac{\gamma a}{4}\right)\right)</math>.</p> | <p>Plate deflection is maximum in the section <math>x = a/2</math>:</p> $ W  = \left  \frac{1}{192} \cdot \frac{pa^3}{D_{pl}} m_1 \right ,$ <p>where <math>m_1 = 1 + \frac{48k}{\pi^2} \left(1 - \frac{2D_{ll}\eta}{D_{pl}}\right) \times \left(1 - \frac{4th(\gamma a/4)}{\gamma a}\right)</math>.</p>        |

| Type of load                                                                                                                                                                                  | Stresses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Deflections                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p>Plate edges are freely supported, the transverse load is uniformly distributed in the random section</p> | <p>In such case, for <math>G_{core}/E</math> the following condition shall be met:<br/> <math>2,0 \cdot 10^{-4} \leq G_{core}/E \leq 2,0 \cdot 10^{-3}</math>.<br/>                     The formulae may be used where the following condition is met:<br/> <math>-a/2 \leq x \leq \xi</math>.</p> <p>Normal stresses in load-bearing layers are maximum at <math>x = \xi</math>; <math>z = \pm(h + \delta)</math>:</p> $ \sigma_x  = \left  \frac{p}{D1_{pl}} \cdot \frac{E_{ll}}{1-\mu_{ll}^2} (h + \delta) \left[ 2C_3\xi + C_4 + \frac{k1^2}{(h+\delta)} \times \left( \frac{D_{ll}}{B_{ll}(h+\delta/2)} - \delta/2 \right) (C_5 \cdot sh(k1\xi) + C_6 \cdot ch(k1\xi)) \right] \right ,$ <p>tangential stresses in the core are maximal at <math>-a/2 \leq x \leq \xi</math>; <math>z = 0</math> (at <math>\xi \leq 0</math>):</p> $ \tau_{xz}  = \frac{p}{D1_{pl}} \cdot 2B_{ll}(h + \delta/2) \left[ C_3 + \frac{D_{ll}k1^3}{2B_{ll}(h+\delta/2)^2} \times (C_5 \cdot ch(-k1a/2) + C_6 \cdot sh(-k1a/2)) \right]  $ <p>where <math>D1_{pl} = 2(D_{ll} + B_{ll}(h + \delta/2)^2)</math>,<br/> <math>k1 = \sqrt{\frac{G_{core}D1_{pl}}{2B_{ll}D_{ll}h}}</math>, <math>C_3 = \frac{a/2-\xi}{2a}</math>, <math>C_4 = \frac{a/2-\xi}{2}</math>,<br/> <math>C_5 = \frac{B_{ll}(h+\delta/2)^2 \cdot sh(k1(a/2-\xi))}{2D_{ll}k1^3 \cdot ch(k1a/2)}</math>,<br/> <math>C_6 = \frac{B_{ll}(h+\delta/2)^2 \cdot sh(k1(a/2-\xi))}{2D_{ll}k1^3 \cdot ch(k1a/2)}</math>.</p> | <p>Plate deflection is determined by the formula</p> $ W  = \left  \frac{p}{D1_{pl}} \cdot \left[ C_2 - C_1 \cdot x + C_3 \cdot \left( \frac{2 \cdot B_{ll} \cdot (h + \delta/2)}{G_{core}} - \frac{x^2}{3} \right) \cdot x - \frac{C_4 \cdot x^2}{2} + C_5 \cdot sh(k1 \cdot x) + C_6 \cdot ch(k1 \cdot x) \right] \right ,$ <p>where <math>C_1 = \frac{a/2-\xi}{2a} \left( \frac{2B_{ll}(h+\delta/2)^2}{D_{ll}k1^2 \cdot d} - \frac{\xi}{3}(a-\xi) \right)</math>,<br/> <math>C_2 = \frac{a/2-\xi}{4} \left( \frac{2B_{ll}(h+\delta/2)^2}{D_{ll}k1^2} + \frac{\xi}{3}(a-\xi) + \frac{a^2}{6} \right)</math>,<br/> <math>C_3 = \frac{a/2-\xi}{2a}</math>, <math>C_4 = \frac{a/2-\xi}{2}</math>,<br/> <math>C_5 = \frac{B_{ll}(h+\delta/2)^2 \cdot sh(k1(a/2-\xi))}{2D_{ll}k1^3 \cdot sh(k1a/2)}</math>,<br/> <math>C_6 = -\frac{B_{ll}(h+\delta/2)^2 \cdot sh(k1(a/2-\xi))}{2D_{ll}k1^3 \cdot ch(k1a/2)}</math>,<br/> <math>D1_{pl} = 2(D_{ll} + B_{ll}(h + \delta/2)^2)</math>,<br/> <math>k1 = \sqrt{\frac{G_{core}D1_{pl}}{2B_{ll}D_{ll}h}}</math>,<br/> <math>d = \frac{B_{ll}h(h+\delta/2)}{D_{ll} + (B_{ll}d/2)(h+\delta/2)}</math>.</p> <p>Plate deflection is maximum in the section, with coordinate <math>\partial W / \partial x = 0</math> and within the range <math>-a/2 \leq x \leq \xi</math>; (plate deflection at <math>x = \xi</math> differs from the maximum value by not more than 10 %)</p> |

| Type of load                                                                                                                                                                                  | Stresses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Deflections                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p>Laminate edges are free-standing, the transverse load is distributed according to the triangular law</p> | <p>Normal stresses in load-bearing layers are maximum at</p> $x = x_2 = \sqrt{\frac{a^2}{3} + \frac{hB_{II}\delta}{G_{core}(h+\delta)}}; z = \pm(h + \delta)$ <p>and determined by the formula</p> $ \sigma_x  = \left  \frac{q_0 x_2}{2h+\delta} \times \left( \frac{2(h+\delta)}{\delta(2h+\delta)} \left( \frac{hB_{II}}{G_{core}} + \frac{a^2+x_2^2}{6} \right) - \frac{hB_{II}}{\delta G_{core}} \right) \right ,$ <p>shear stresses in the core are maximum at <math>x = a; z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{q_0 a^2}{3(2h+\delta)} \right ,$ <p>where <math>q_0 = \frac{q_{max}}{a}</math>,</p> <p><math>q_{max}</math> = maximum distributed transverse load per surface area.</p> | <p>Plate deflection is maximum in the section at</p> $x = x_1 = \sqrt{\frac{3m_1(10a^2+m_2)-\sqrt{m_3}}{30m_1}};$ <p>and is determined by the formula</p> $ W  = \left  \frac{q_0 x_1}{180B_{II}(2h+\delta)^2} \times \left( 7a^4 - 10a^2x_1^2 + 3x_1^4 + 60 \frac{hB_{II}}{G_{core}} (a^2 + x_1^2) \right) \right ,$ <p>where <math>m_1 = \frac{q_0}{180B_{II}(2h+\delta)^2}</math>,</p> $m_2 = \frac{60hB_{II}}{G_{core}},$ $m_3 = \left( 3m_1(10a^2 + m_2) \right)^2 - 60m_1^2(7a^4 + m_2a^2),$ <p>where <math>q_0 = \frac{q_{max}}{a}</math>,</p> <p><math>q_{max}</math> = maximum distributed transverse load per surface area.</p> |

## 7 STRESS-STRAIN BEHAVIOR OF SANDWICH PLATES AT CYLINDRICAL BENDING EXPOSED TO LOCAL LOADS

This Section contains the formulae to determine maximum deflections, maximum normal stresses in load-bearing layers and maximum shear stresses in the core for sandwich plates with isotropic core of the FRP hull structures. The sandwich plate cylindrical bending ([Fig. 6](#)) when exposed to local loads is considered.

### Symbols.

For the purpose of this Section, the following symbols have been adopted:

$\delta$  = thickness of each load-bearing layer, in m;

$h$  = half thickness of the sandwich plate core, in m;

$E_{ll}$  = Young's modulus of load-bearing layers made of isotropic material, in Pa;

$\mu_{ll}$  = Poisson's ratio of load-bearing layers;

$E_{core}$  = Young's modulus of the isotropic core, in Pa;

$\mu_{core}$  = Poisson's ratio of the isotropic core;

$q$  = uniformly distributed transverse load per surface area, in  $Nm^2$ ;

$p$  = uniformly distributed transverse load per unit length, in  $Nm$ ;

$M$  = intensity of the uniformly distributed moment per unit length, in  $N$ ;

$W$  = maximum deflection of load-bearing layers of the plate, in m;

$\sigma_x$  = maximum normal stresses in load-bearing layers, in Pa;

$\tau_{xz}$  = maximum shear stresses in the isotropic core, in Pa;

Where load-bearing layers are made of the same isotropic material and have the same thickness, the following conditions shall be met:

$$E_i^1 = E_i^2 = E_{ll}, \mu_{ij}^1 = \mu_{ij}^2 = \mu_{ll}, \delta_1 = \delta_2 = \delta$$

where  $i, j = 1, 2$  – directions of coordinate axes;

$E_i^1, E_i^2$  = Young's moduli of load-bearing layers;

$\mu_{ij}^1, \mu_{ij}^2$  = Poisson's ratios of load-bearing layers;

$\delta_1, \delta_2$  = thicknesses of load-bearing layers.

For the core made of isotropic material, the following conditions shall be met:

$$E_i^{core} = E_{core}, \mu_{ij} = \mu_{core}$$

where  $E_i^{core}$  = Young's modulus of the core;

$\mu_{ij}$  = Poisson ratio of the core.

The formulae may be used for calculation of sandwich plates with orthotropic load-bearing layers, where their Young's moduli do not vary more than 20 % (relative to the highest value of the moduli), i.e. the following condition is met:

$$(1 - E_2/E_1) \cdot 100 < 20\% \text{ at } E_1 > E_2.$$

where  $E_1$  and  $E_2$  = Young's moduli of the load-bearing layer in the direction of main reinforcement (direction  $0^\circ$ ) and in the direction  $90^\circ$  to the main reinforcement.

In this case, the arithmetic mean shall be taken as the Young's modulus for calculations.

The values used in the formulae specified in [Table 7](#) are determined by the following formulae: when determine maximum normal stresses acting in the upper load-bearing layer of the plate

$$\sqrt[3]{E_{core}/E_{ll}} \cdot (2h/\delta) \leq 8,0;$$

when determine maximum deflections of the plate

$$\sqrt[3]{E_{core}/E_{ll}} \cdot (2h/\delta) \leq 1,6.$$

The value of the elastic foundation's stiffness factor shall be determined by the following formula:

$$C = \frac{1}{f} \frac{2(1-\mu_{core})}{(1+\mu_{core})(3-4\mu_{core})} \lambda E_{core}$$

where  $f = \frac{(sh(\varepsilon 1))^2 - (\varepsilon 2)^2}{\varepsilon 2 + sh(\varepsilon 1)ch(\varepsilon 1)},$

$$\varepsilon 1 = \lambda 2h,$$

$$\varepsilon 2 = \frac{\lambda 2h}{3-4\mu_{core}},$$

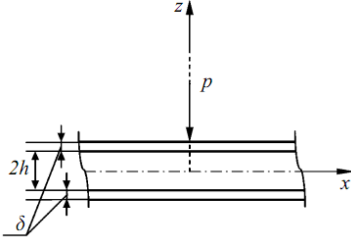
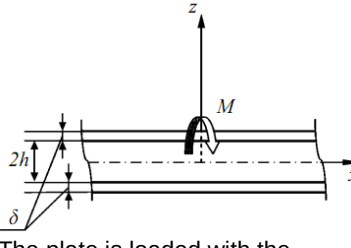
$$\lambda = \pi/a_x, a_x = \pi^3 \sqrt{2D_{ll}/k1},$$

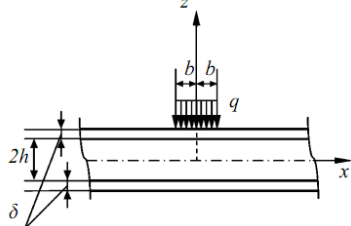
$$D_{ll} = \frac{E_{ll}\delta^3}{12(1-\mu_{ll}^2)},$$

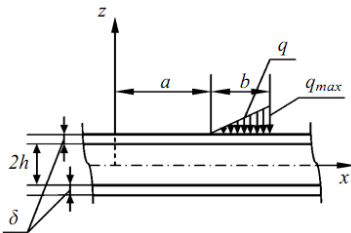
$$k1 = \frac{2(1-\mu_{core})E_{core}}{(1+\mu_{core})(3-4\mu_{core})}.$$

Table 7

**Calculation of stress-strain behavior of sandwich plate at cylindrical bending exposed to local loads**

| Type of load                                                                                                                                                                               | Stresses                                                                                                                                                                                                                                                                                                        | Deflections                                                                                                                                                                                                                                                                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p>The transverse load is uniformly distributed over the plate width in any section</p>                | <p>Normal stresses in load-bearing layers are maximum at <math>x = 0; z = h + \delta</math>:</p> $ \sigma_x  = \left  \frac{3p}{2\delta^2} \sqrt{\frac{E_{ll}\delta^3}{3C}} \right ,$ <p>shear stresses in the core are maximum at <math>x = 0; z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{3p}{8h} \right .$ | <p>Plate deflection is maximum in section at <math>x = 0</math>:</p> $ W  = \left  \frac{p}{2} \sqrt{\frac{3}{C^3 E_{ll} \delta^3}} \right .$                                                                                                                                       |
|  <p>The plate is loaded with the moment uniformly distributed over the plate's width in any section</p> | <p>Normal stresses in load-bearing layers are maximum at <math>x = 0; z = h + \delta</math>:</p> $ \sigma_x  = \left  \frac{3M}{\delta^2} \right ,$ <p>shear stresses in the core are maximum at <math>x = 0; z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{3M}{8h} \sqrt{\frac{3C}{E_{ll}\delta^3}} \right .$  | <p>Plate deflection is determined by the formula</p> $ W  = \left  M \sqrt{\frac{3}{C E_{ll} \delta^3}} e^{-mx} \sin(mx) \right ,$ $m = \sqrt[4]{\frac{3C}{E_{ll}\delta^3}}.$ <p>The plate's deflection is maximum in the section, at <math>\partial W / \partial x = 0</math>.</p> |

| Type of load                                                                                                                                                                       | Stresses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Deflections                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p>The transverse load is uniformly distributed in the local region of the plate in any area</p> | <p>Normal stresses in load-bearing layers are maximum at <math>x = 0</math>; <math>z = h + \delta</math>:</p> $ \sigma_x  = \left  \frac{3qE''}{2} \sqrt{\frac{E_{II}}{3C\delta}} \right ,$ <p>shear stresses are maximum at <math>x = \pm b</math>; <math>z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{3q}{4h} \sqrt{\frac{E_{II}\delta^3}{3C}} (-0,25E_\beta C_\varphi''' - 0,25E_\beta'' C_\varphi') \right ,$ <p>where <math>C_\varphi' = sh(\varphi) \cos(\varphi) - ch(\varphi) \sin(\varphi)</math>,<br/> <math>C_\varphi''' = -2 \cdot (sh(\varphi) \cdot \cos(\varphi) + ch(\varphi) \cdot \sin(\varphi))</math>,<br/> <math>C_\beta = ch(\beta) \cos(\beta)</math>,<br/> <math>C_\beta' = sh(\beta) \cos(\beta) - ch(\beta) \sin(\beta)</math>,<br/> <math>C_\beta'' = -2sh(\beta) \sin(\beta)</math>,<br/> <math>C_\beta''' = -2 \cdot (sh(\beta) \cdot \cos(\beta) + ch(\beta) \cdot \sin(\beta))</math>,<br/> <math>E_\beta = C_\beta - 0,5C_\beta' + 0,25C_\beta'''</math>,<br/> <math>E_\beta'' = -C_\beta' + C_\beta'' - 0,5C_\beta'''</math>,<br/> <math>\varphi = xm</math>, <math>\beta = bm</math>, <math>m = \sqrt[4]{\frac{3C}{E_{II}\delta^3}}</math>.</p> | <p>Plate deflection is maximum in section at <math>x = 0</math>:</p> $ W  = \left  \frac{q(1-E_\beta)}{C} \right ,$ <p>where <math>C_\beta = ch(\beta) \cos(\beta)</math>,<br/> <math>C_\beta' = sh(\beta) \cos(\beta) - ch(\beta) \sin(\beta)</math>,<br/> <math>C_\beta''' = -2 \cdot (sh(\beta) \cdot \cos(\beta) + ch(\beta) \cdot \sin(\beta))</math>,<br/> <math>E_\beta = C_\beta - 0,5C_\beta' + 0,25C_\beta'''</math>,<br/> <math>\beta = bm</math>, <math>m = \sqrt[4]{\frac{3C}{E_{II}\delta^3}}</math>.</p> |

| Type of load                                                                                                                                                                                                     | Stresses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Deflections                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  <p>The transverse load distributed according to the triangular law is applied in the local region of the plate in any area</p> | <p>The distributed load value depending on the section coordinate is determined by the formula <math>q = q_{max} (x - a)/b</math> in such case, parameter <math>a</math> shall be selected to meet the following condition: <math>20\delta \leq a \leq 30\delta</math>.</p> <p>Values of normal stresses in the load application area are determined by the formula</p> $ \sigma_x  = \left  \frac{6q_{max}}{\beta m^2 \delta^2} \times (0,25A2 \cdot C_\varphi'' + 0,25B2 \cdot C_\varphi''' - C2C_\varphi - D2C_\varphi') \right ,$ <p>normal stresses are maximum in the section at <math>\partial\sigma_x/\partial x = 0</math>, если <math>z = h + \delta</math>; shear stresses are maximum at <math>x = a + b</math>; <math>z = 0</math>:</p> $ \tau_{xz}  = \left  \frac{3q_{max}}{4\beta m h} \times (0,25A2 \cdot C_\varphi''' + B2 \cdot C_\varphi - C2C_\varphi' - D2C_\varphi'') \right ,$ <p>where <math>C_\varphi = ch(\varphi) \cos(\varphi)</math>,<br/> <math>C_\varphi' = sh(\varphi) \cos(\varphi) - ch(\varphi) \sin(\varphi)</math>,<br/> <math>C_\varphi'' = -2sh(\varphi) \sin(\varphi)</math>,<br/> <math>C_\varphi''' = -2 \cdot (sh(\varphi) \cdot \cos(\varphi) + ch(\varphi) \cdot \sin(\varphi))</math>,<br/> <math>C_\alpha' = sh(\alpha) \cos(\alpha) - ch(\alpha) \sin(\alpha)</math>,<br/> <math>C_\alpha'' = -2sh(\alpha) \sin(\alpha)</math>,<br/> <math>C_{\alpha\beta} = ch(\alpha + \beta) \cos(\alpha + \beta)</math>,<br/> <math>C_{\alpha\beta}' = sh(\alpha + \beta) \cos(\alpha + \beta) - ch(\alpha + \beta) \sin(\alpha + \beta)</math>,<br/> <math>C_{\alpha\beta}'' = -2sh(\alpha + \beta) \sin(\alpha + \beta)</math>,<br/> <math>C_{\alpha\beta}''' = -2 \cdot (sh(\alpha + \beta) \cdot \cos(\alpha + \beta) + ch(\alpha + \beta) \cdot \sin(\alpha + \beta))</math>,<br/> <math>E_{\alpha\beta}' = -C_{\alpha\beta} + C_{\alpha\beta}' - 0,5C_{\alpha\beta}''</math>,<br/> <math>E_{\alpha\beta}'' = -C_{\alpha\beta}' + C_{\alpha\beta}'' - 0,5C_{\alpha\beta}'''</math>,<br/> <math>E_{\alpha\beta}''' = 2C_{\alpha\beta} + C_{\alpha\beta}' + C_{\alpha\beta}''</math>,<br/> <math>A2 = 0,5(-\beta E_{\alpha\beta}''' + E_{\alpha\beta}'' + C_\alpha' - C_\alpha'')</math>,<br/> <math>B2 = 0,25C_\alpha''</math>,<br/> <math>C2 = -0,25C_\alpha'</math>,<br/> <math>D2 = 0,25(\beta E_{\alpha\beta}'' - E_{\alpha\beta}' + C_\alpha' - 0,5C_\alpha'')</math>,<br/> <math>\alpha = am, \beta = bm, m = \sqrt[4]{\frac{3C}{E_{II}\delta^3}}</math>.</p> <p>when determine normal stresses <math>\varphi = xm</math>,<br/> when determine shear stresses<br/> <math>\varphi = (a + b)m</math></p> | <p>The plate deflection in the area of load application is determined by the formula</p> $ W  = \frac{q_{max}}{\beta C} \times (F + [A2 \cdot C_\varphi + B2 \cdot C_\varphi' + C2 \cdot C_\varphi'' + D2 \cdot C_\varphi''']),$ <p>plate's deflection is maximum in the section at <math>\partial W/\partial x = 0</math>,</p> <p>where <math>C_\varphi = ch(\varphi) \cos(\varphi)</math>,<br/> <math>C_\varphi' = sh(\varphi) \cos(\varphi) - ch(\varphi) \sin(\varphi)</math>,<br/> <math>C_\varphi'' = -2sh(\varphi) \sin(\varphi)</math>,<br/> <math>C_\varphi''' = -2 \cdot (sh(\varphi) \cdot \cos(\varphi) + ch(\varphi) \cdot \sin(\varphi))</math>,<br/> <math>C_\alpha' = sh(\alpha) \cos(\alpha) - ch(\alpha) \sin(\alpha)</math>,<br/> <math>C_\alpha'' = -2sh(\alpha) \sin(\alpha)</math>,<br/> <math>C_{\alpha\beta} = ch(\alpha + \beta) \cos(\alpha + \beta)</math>,<br/> <math>C_{\alpha\beta}' = sh(\alpha + \beta) \cos(\alpha + \beta) - ch(\alpha + \beta) \sin(\alpha + \beta)</math>,<br/> <math>C_{\alpha\beta}'' = -2sh(\alpha + \beta) \sin(\alpha + \beta)</math>,<br/> <math>C_{\alpha\beta}''' = -2 \cdot (sh(\alpha + \beta) \cdot \cos(\alpha + \beta) + ch(\alpha + \beta) \cdot \sin(\alpha + \beta))</math>,<br/> <math>E_{\alpha\beta}' = -C_{\alpha\beta} + C_{\alpha\beta}' - 0,5C_{\alpha\beta}''</math>,<br/> <math>E_{\alpha\beta}'' = -C_{\alpha\beta}' + C_{\alpha\beta}'' - 0,5C_{\alpha\beta}'''</math>,<br/> <math>E_{\alpha\beta}''' = 2C_{\alpha\beta} + C_{\alpha\beta}' + C_{\alpha\beta}''</math>,<br/> <math>A2 = 0,5(-\beta E_{\alpha\beta}''' + E_{\alpha\beta}'' + C_\alpha' - C_\alpha'')</math>,<br/> <math>B2 = 0,25C_\alpha''</math>,<br/> <math>C2 = 0,25C_\alpha'</math>,<br/> <math>D2 = 0,25(\beta E_{\alpha\beta}'' - E_{\alpha\beta}' + C_\alpha' - 0,5C_\alpha'')</math>,<br/> <math>\alpha = am, \beta = bm, \varphi = xm</math>,<br/> <math>m = \sqrt[4]{\frac{3C}{E_{II}\delta^3}}</math>,<br/> <math>F = \varphi - \alpha</math>.</p> |

## 8 STRESS-STRAIN BEHAVIOR OF SANDWICH PLATES AT BENDING

### 8.1 Plate edges are freely supported, the transverse load is uniformly distributed.

The formulae to determine maximum deflections, maximum normal stresses in load-bearing layers and maximum shear stresses in the core for symmetric sandwich plates with same thickness isotropic outer layers and transversally isotropic core with the isotropy plane matching the plate plane are given in 8.2. Transverse deflection of sandwich plates is considered. The load shall be perpendicular to the plate plane.

The formulae may also be used for calculation of plates with isotropic core.

Symbols.

For the purpose of this Section, the following symbols have been adopted:

$a$  = plate length, in m;

$b$  = plate width, in m;

$\delta$  = thickness of each load-bearing layer, in m;

$h$  = half thickness of the sandwich plate core, in m;

$E_{bl}$  = Young's modulus of load-bearing layers in the sandwich plate, in Pa;

$\nu_{12(bl)}$  = Poisson's ratio of the material of load-bearing layers in the sandwich plate;

$E_{core}$  = Young's modulus of core in isotropy plane of the sandwich plate, in Pa;

$G_{core}$  = shear modulus of the core in plane that is orthogonal to the isotropy plane of the sandwich plate, in Pa;

$\nu_{core}$  = Poisson's ratio of the core of sandwich plate;

$p$  = uniformly distributed load, in N/m<sup>2</sup>;

$w$  = maximum deflection of load-bearing layers of the plate, in m;

$\sigma_x, \sigma_y$  = maximum normal stresses in load-bearing layers, in Pa;

$\tau_{xz}, \tau_{yz}$  = maximum shear stresses in the core, in Pa.

Calculations as per Formulae in 8.2 may be performed if the following conditions are met:

$$\frac{G_{core}}{E_{bl}} (1 - \nu_{12(bl)}^2) > 0,005 \text{ at } \frac{2h}{a} \sqrt{1 + \left(\frac{a}{b}\right)^2} \leq 0,3 \text{ and } 0,01 \leq \frac{\delta}{h} \leq 0,5.$$

### 8.2 Plate deflection is maximum at point $x = a/2, y = b/2$ and determined by the formula

$$|w|_{x=a/2, y=b/2} = \frac{8p}{\pi^2 G_{core}} m_1,$$

$$\text{where } m_1 = \sum_{i=0}^N \sum_{j=0}^N (-1)^{(m-1)/2} (-1)^{(n-1)/2} \frac{1}{d \cdot m \cdot n \cdot r} \left( k_1 \operatorname{ch}(r_1 h) + \frac{B_{ll} r}{G_{core}} \operatorname{sh}(r_1 h) \right);$$

$$B_{ll} = \frac{E_{bl} \delta}{1 - \nu_{12(bl)}^2};$$

$2h$  = core thickness of the sandwich plate;

$$m = 2i + 1, n = 2j + 1, \alpha = m\pi/a, b = n\pi/b;$$

$$r^2 = \alpha^2 + \beta^2, r_1 = rk_1;$$

$$k_1 = \sqrt{\frac{E_{core}}{(1 - \nu_{core}^2) G_{core}}};$$

$$d = \left( h + \frac{B_{ll} \delta^2 r^2}{3G_{core}} \right) r_1 \operatorname{ch}(r_1 h) - \left( 1 - \frac{B_{ll} r^2}{G_{core}} \left( h + \delta + \frac{B_{ll} \delta^2 r^2}{12G_{core}} \right) \right) \operatorname{sh}(r_1 h).$$

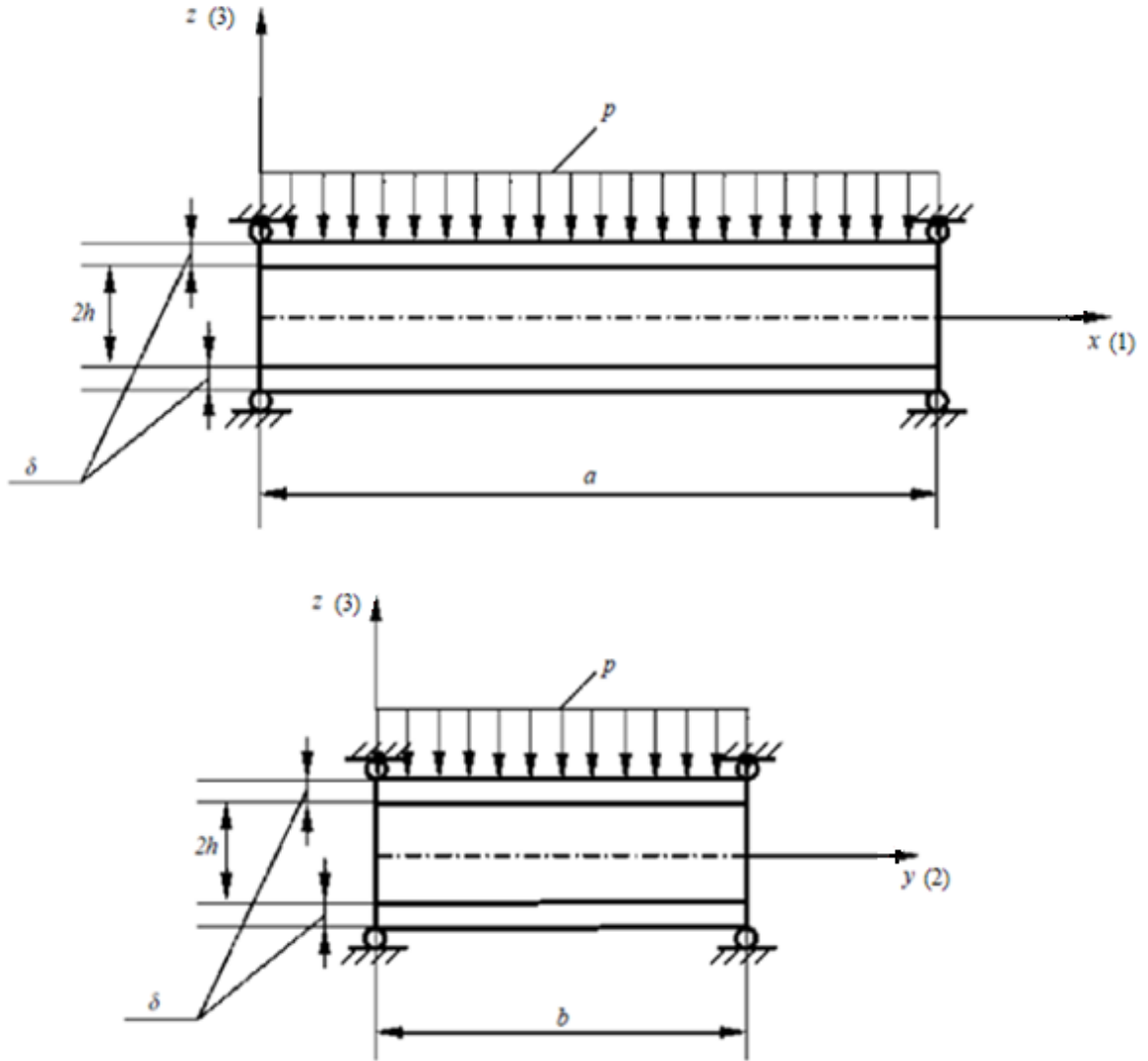


Fig. 8.1  
Load type of the sandwich plate

Normal stresses in load-bearing layers  $\sigma_x$  and  $\sigma_y$  are maximum at  $x = a/2$ ,  $y = b/2$  and determined by the following formulae:

$$|\sigma_x|_{x=a/2, y=b/2} = \frac{8pE_{bl}}{(1-v_{12}^2(bl))\pi^2 G_{core}} m_2,$$

$$m_2 = \sum_{i=0}^N \sum_{j=0}^N (-1)^{(m-1)/2} (-1)^{(n-1)/2} \frac{1}{d \cdot m \cdot n \cdot r^2} (\alpha^2 + v_{12(bl)} \beta^2) \left( \delta r_1 \operatorname{ch}(r_1 h) + \left( 1 + \frac{B_{ll} \delta r^2}{2G_{core}} \right) \operatorname{sh}(r_1 h) \right);$$

$$|\sigma_y|_{x=a/2, y=b/2} = \frac{8pE_{bl}}{(1-v_{12}^2(bl))\pi^2 G_{core}} m_3,$$

$$m_3 = \sum_{i=0}^N \sum_{j=0}^N (-1)^{(m-1)/2} (-1)^{(n-1)/2} \frac{1}{d \cdot m \cdot n \cdot r^2} (\beta^2 + v_{12(bl)} \alpha^2) \left( \delta r_1 \operatorname{ch}(r_1 h) + \left( 1 + \frac{B_{ll} \delta r^2}{2G_{core}} \right) \operatorname{sh}(r_1 h) \right).$$

Shear stresses in the core  $\tau_{xz}$  are maximum at  $x = 0$ ;  $a, y = b/2$  and determined by the formula

$$|\tau_{xz}|_{x=0; a, y=b/2} = \frac{8pB_{II}}{\pi a G_{core}} m_4,$$

$$\text{where } m_4 = \sum_{i=0}^N \sum_{j=0}^N (-1)^{(n-1)/2} \frac{1}{d \cdot n} \cdot \left( \text{sh}(r_1 h) + \frac{r_1 \delta}{2} + \frac{r_1 G_{core}}{B_{II} r^2} (\text{ch}(r_1 h) - 1) \right).$$

Shear stresses in the core  $\tau_{yz}$  are maximum at  $x = 0$ ;  $a, y = b/2$  and determined by the formula

$$|\tau_{yz}|_{x=a/2; y=0; b} = \frac{8pB_{II}}{\pi b G_{core}} m_5,$$

$$\text{where } m_5 = \sum_{i=0}^N \sum_{j=0}^N (-1)^{(m-1)/2} \frac{1}{d \cdot m} \cdot \left( \text{sh}(r_1 h) + \frac{r_1 \delta}{2} + \frac{r_1 G_{core}}{B_{II} r^2} (\text{ch}(r_1 h) - 1) \right).$$

$N$  is taken so that the difference between values of neighboring terms of series does not exceed 5 %.

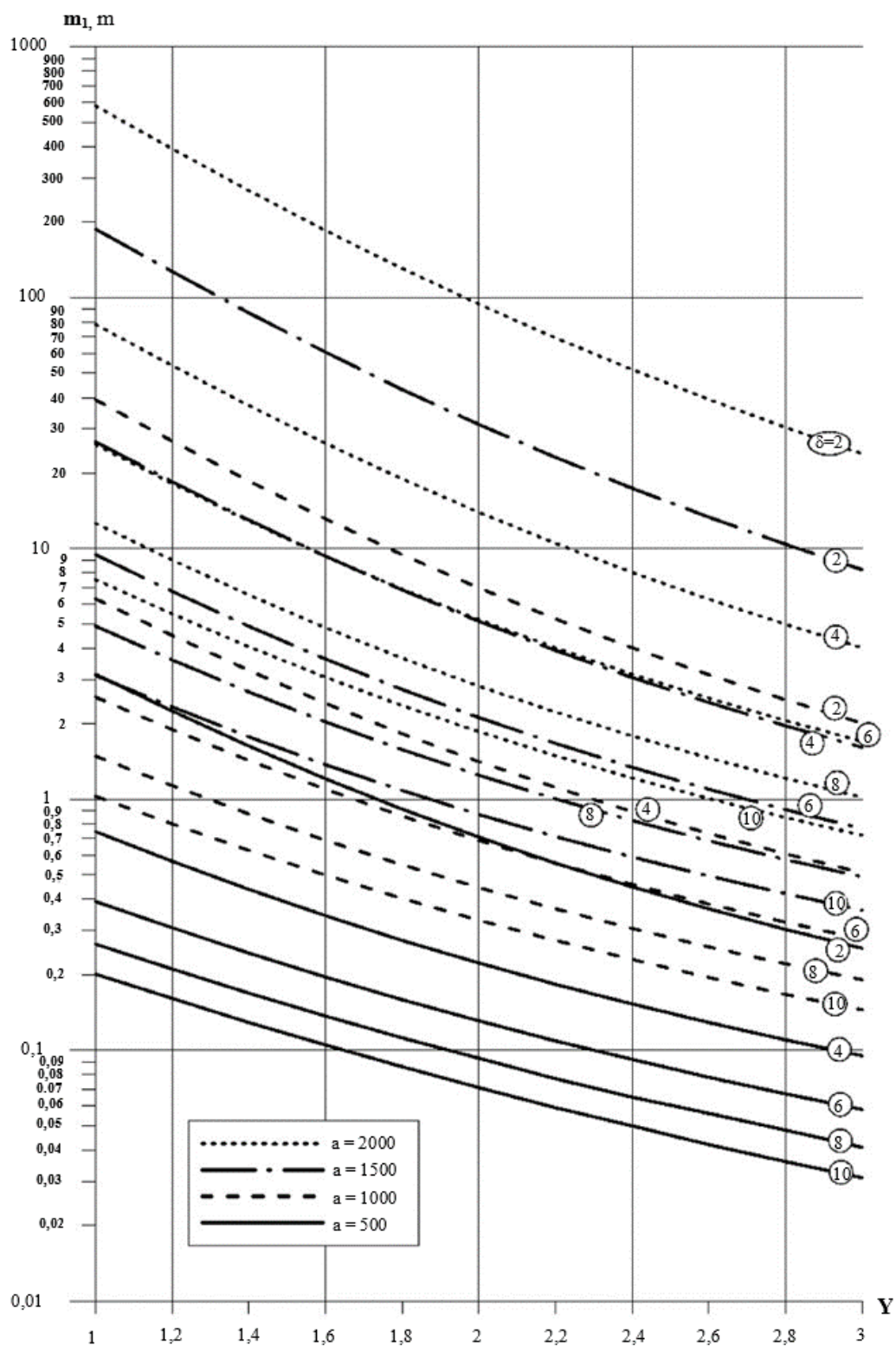
Values of factors  $m_i$ ,  $i = \overline{1,5}$  for sandwich plates with the most rational geometric and physical properties  $h/\delta = 5$  and  $v_{core} = 0,38 \div 0,4$  are specified in [Figs. 8.2-1 — 8.2-15](#).

For other values of  $h/\delta$  and  $v_{core}$ , factors  $m_i$ ,  $i = \overline{1,5}$  are determined by the formulae specified in this Section.

Values of  $\gamma$  and  $\eta$  are determined by the following formulae (refer to [Figs. 8.2-1 — 8.2-15](#)):

$$\gamma = a/b;$$

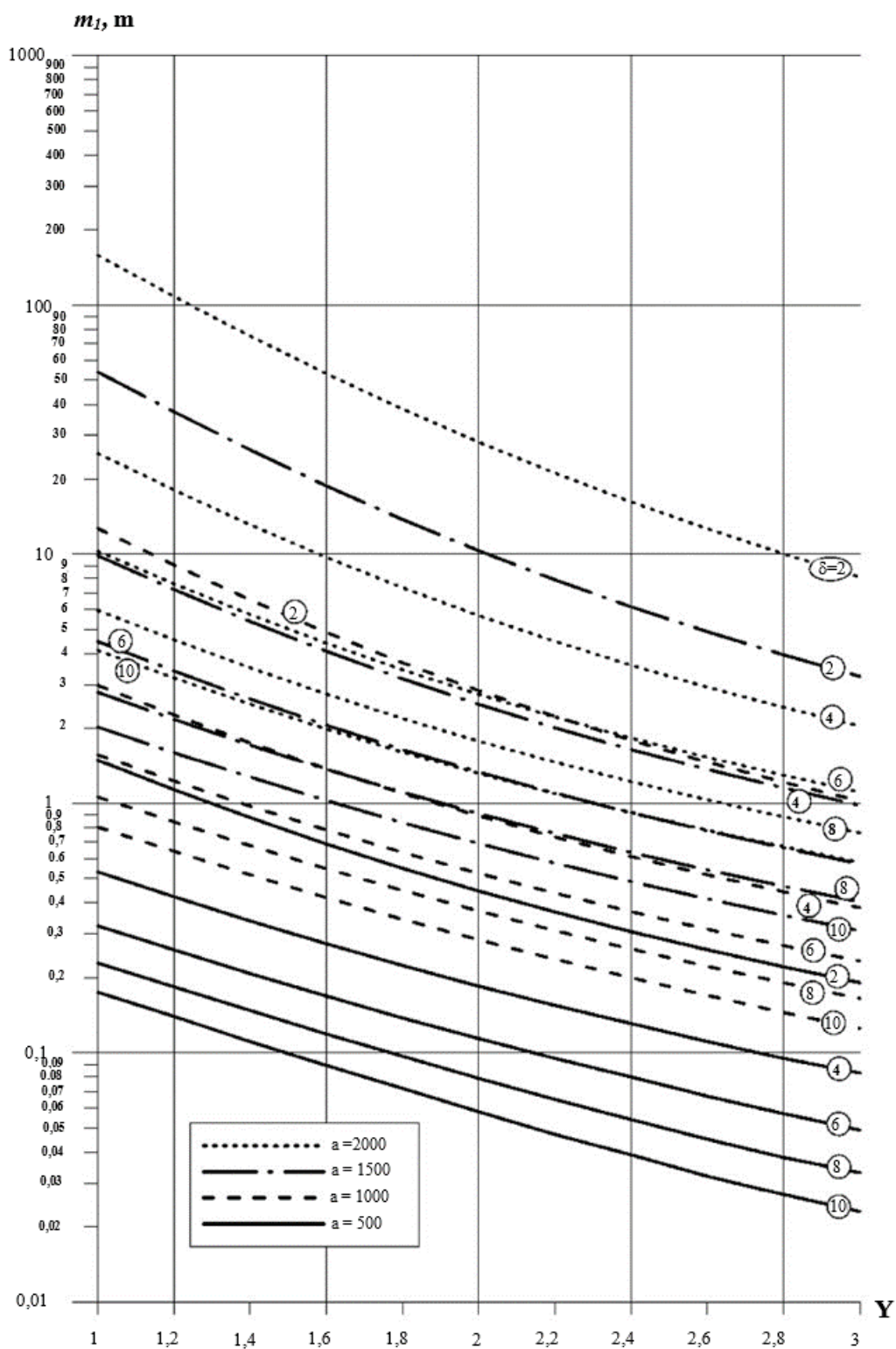
$$\eta = E_{bl}/E_{core}.$$



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles

Fig. 8.2-1

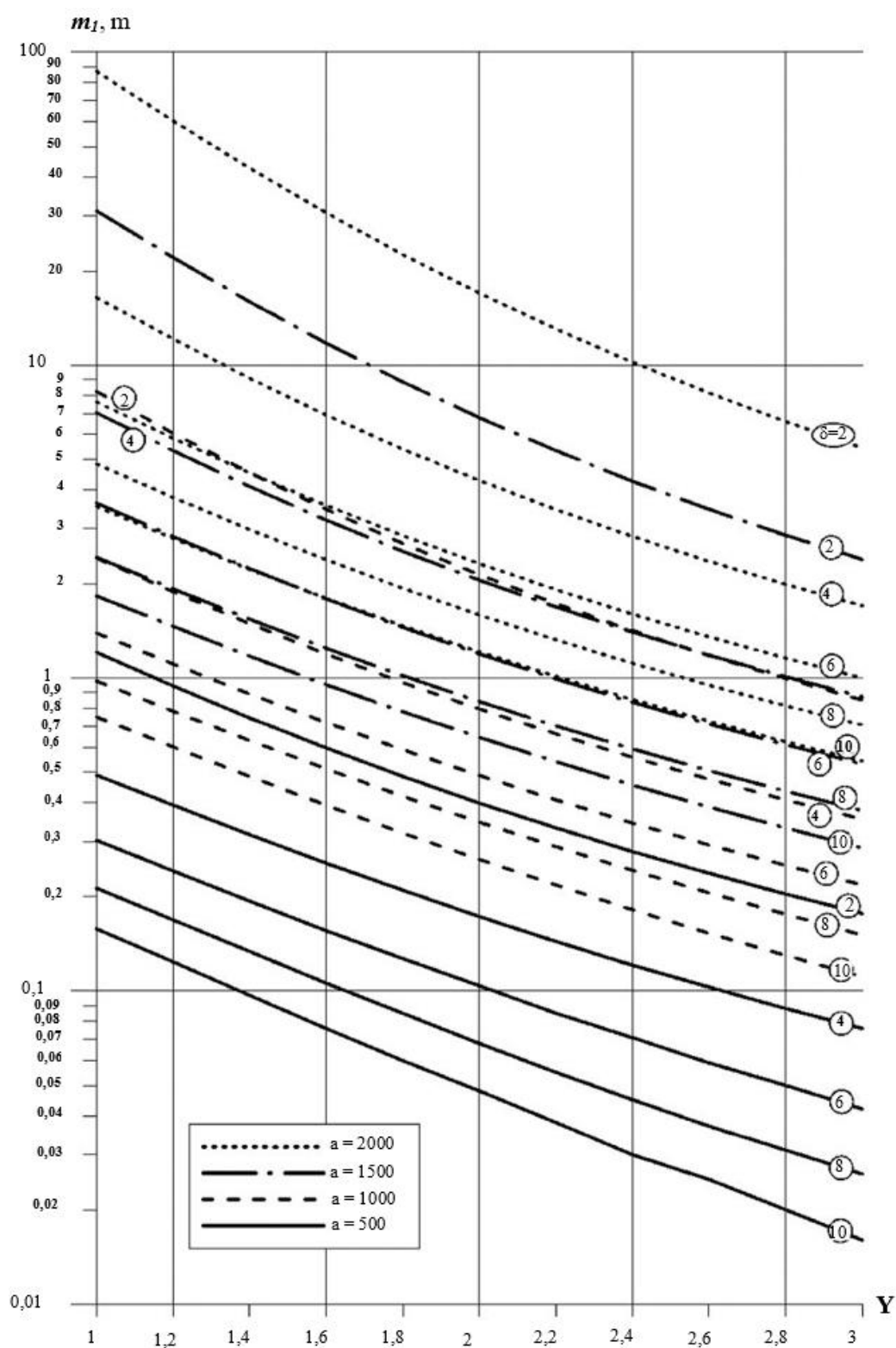
Values of factor  $m_1$  at  $\eta = 100$  for sandwich plates having length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles

Fig. 8.2-2

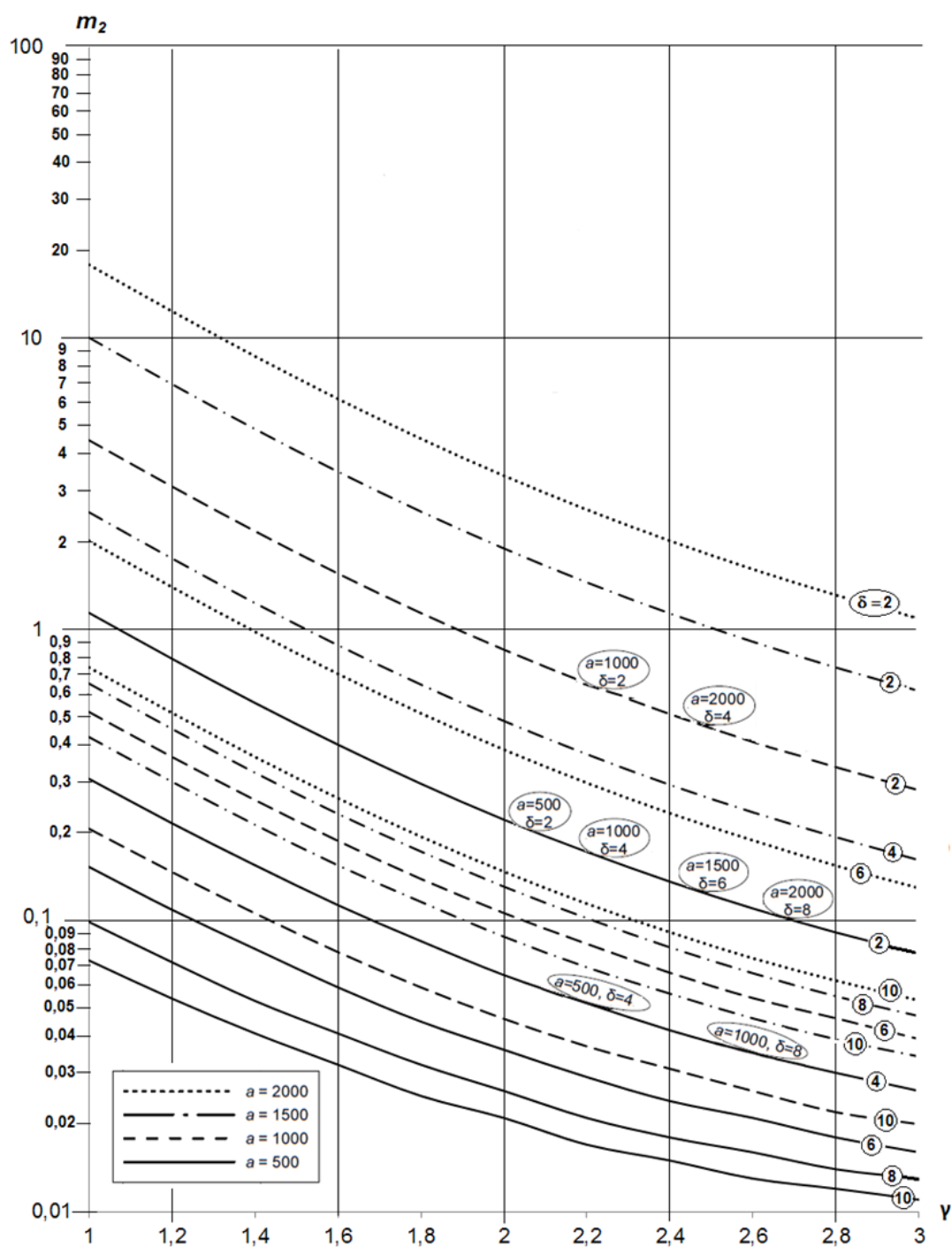
Values of factor  $m_1$  at  $\eta = 400$  for sandwich plates having length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles

Fig. 8.2-3

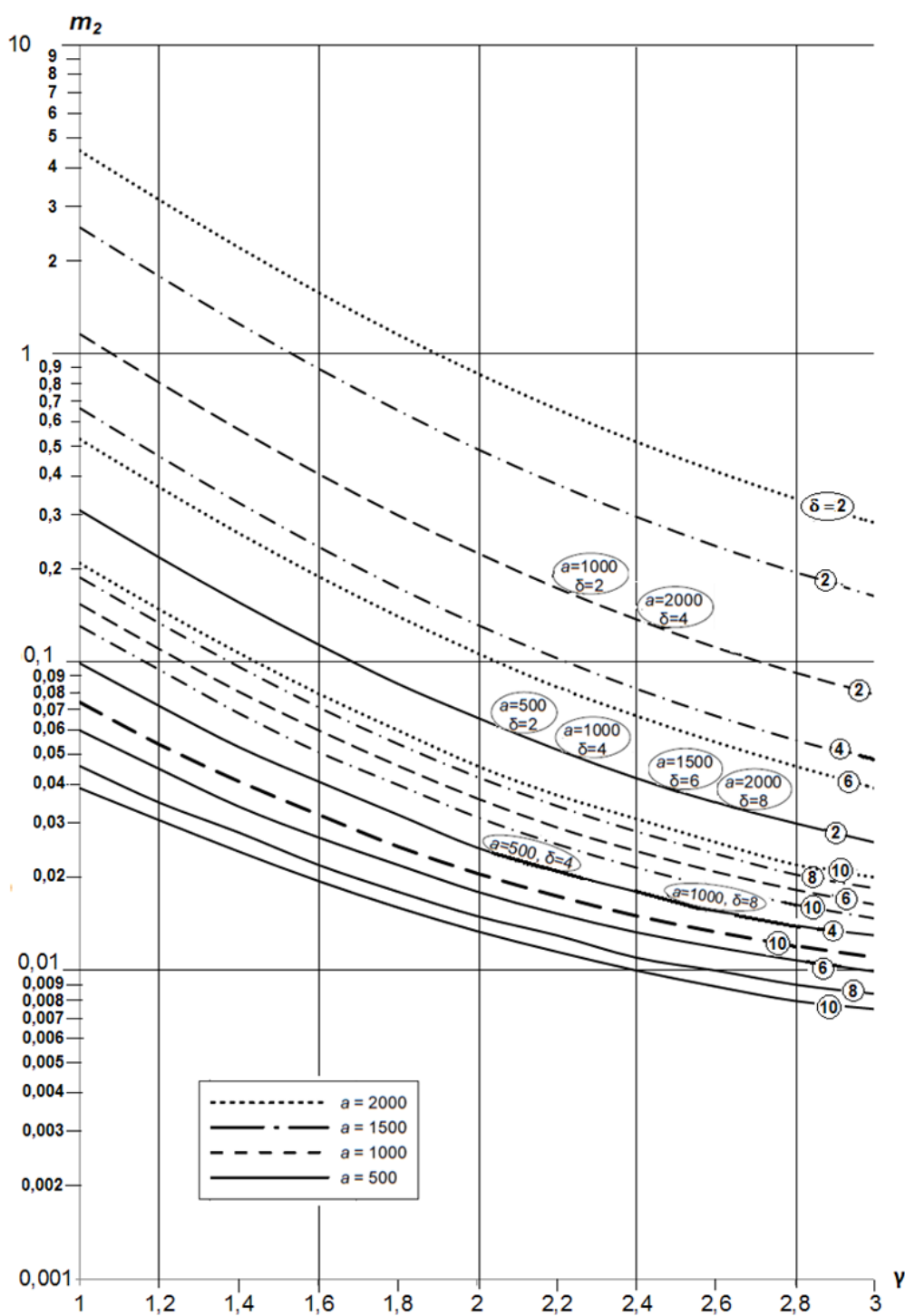
Values of factor  $m_1$  at  $\eta = 800$  for sandwich plates having length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_2$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-4

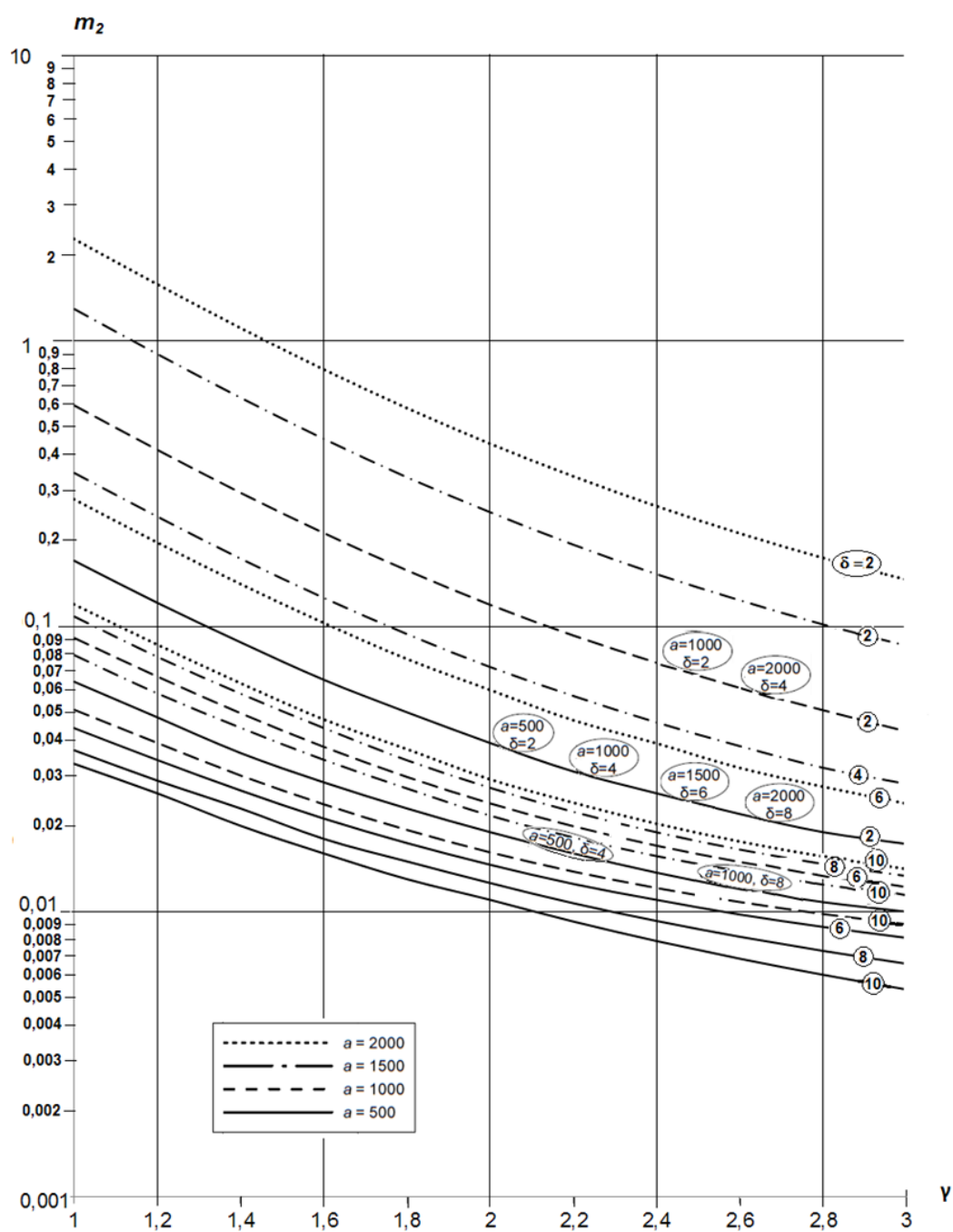
Values of factor  $m_2$  at  $\eta = 100$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_2$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-5

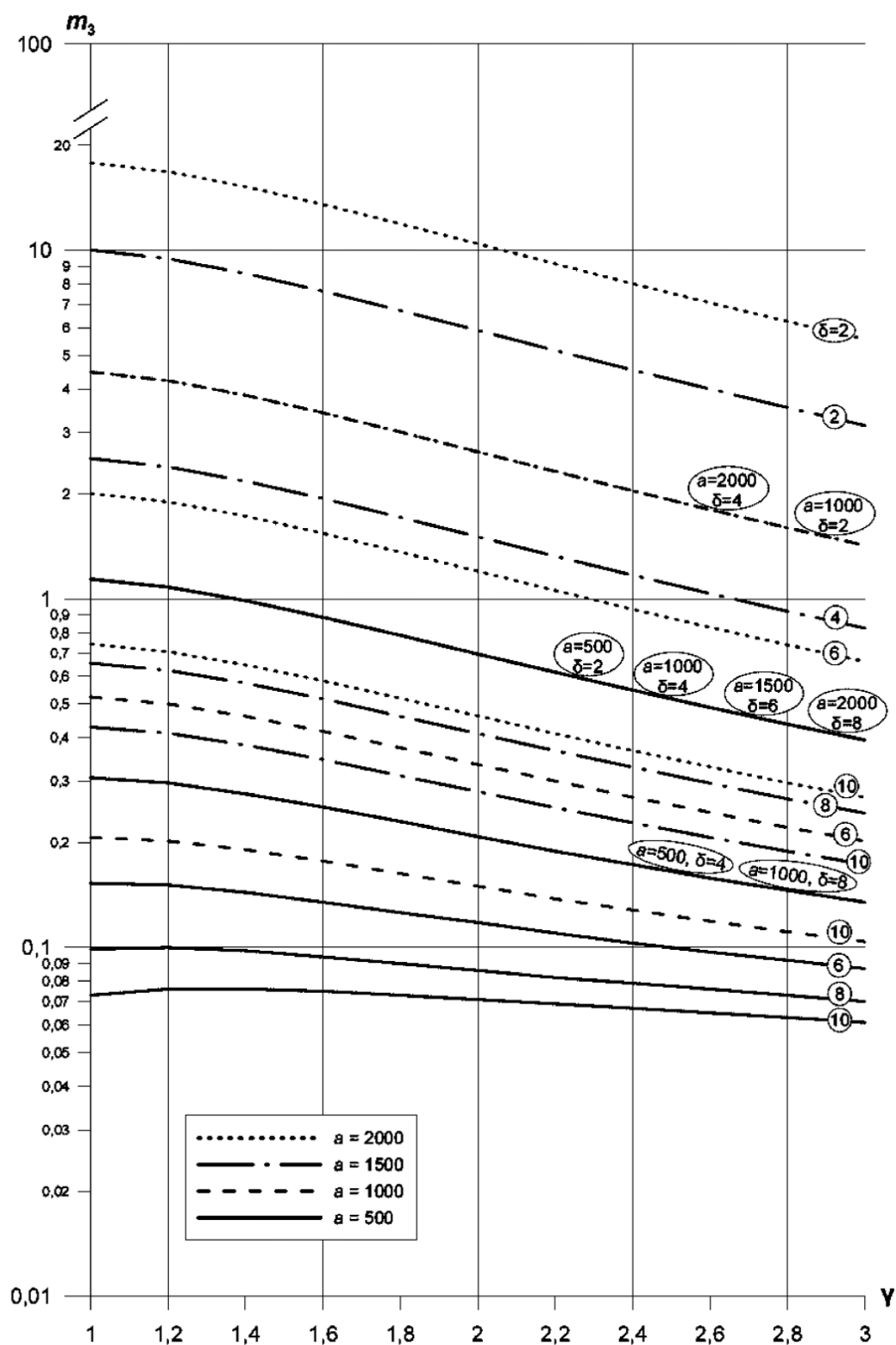
Values of factor  $m_2$  at  $\eta = 400$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_2$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-6

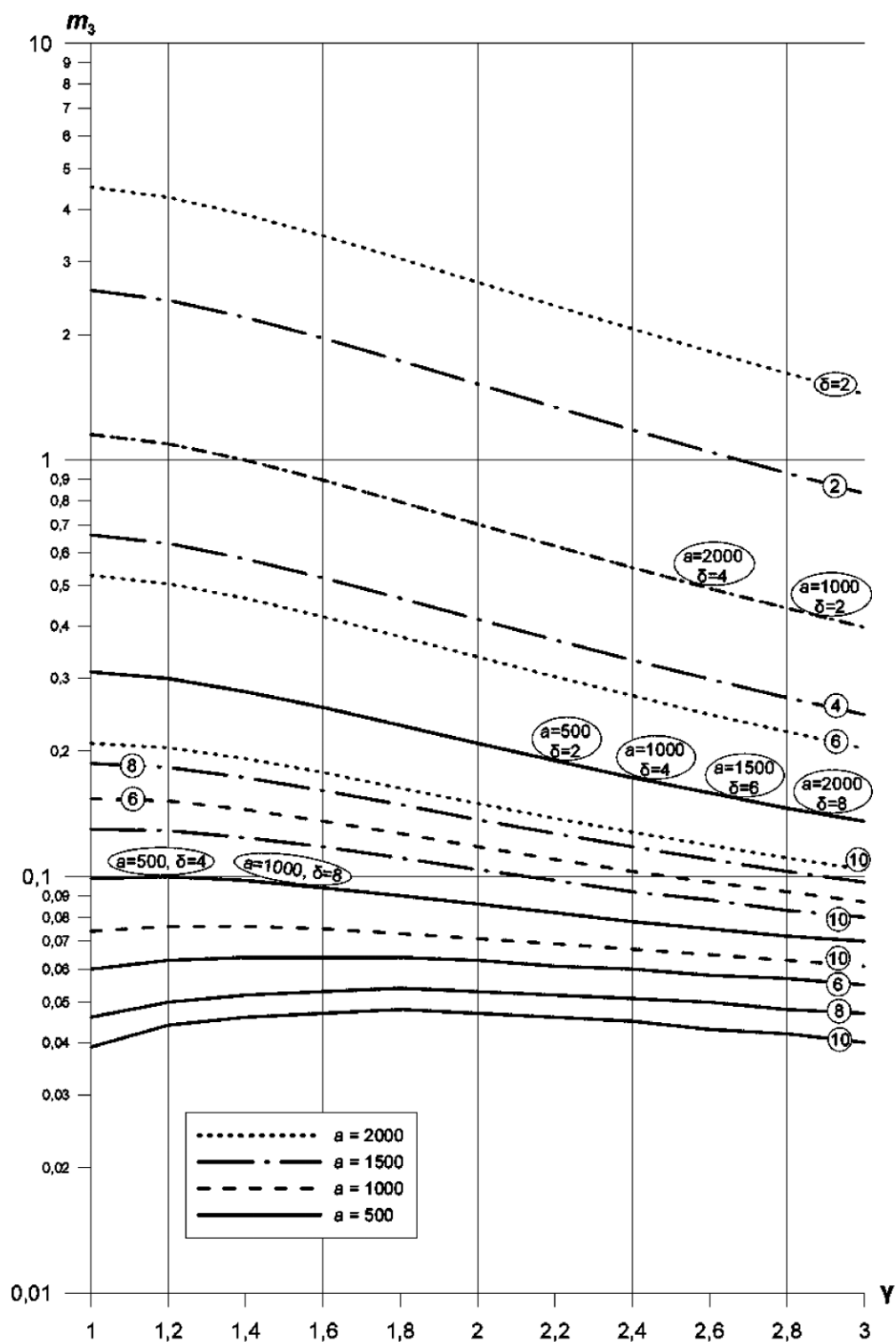
Values of factor  $m_2$  at  $\eta = 800$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_3$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-7

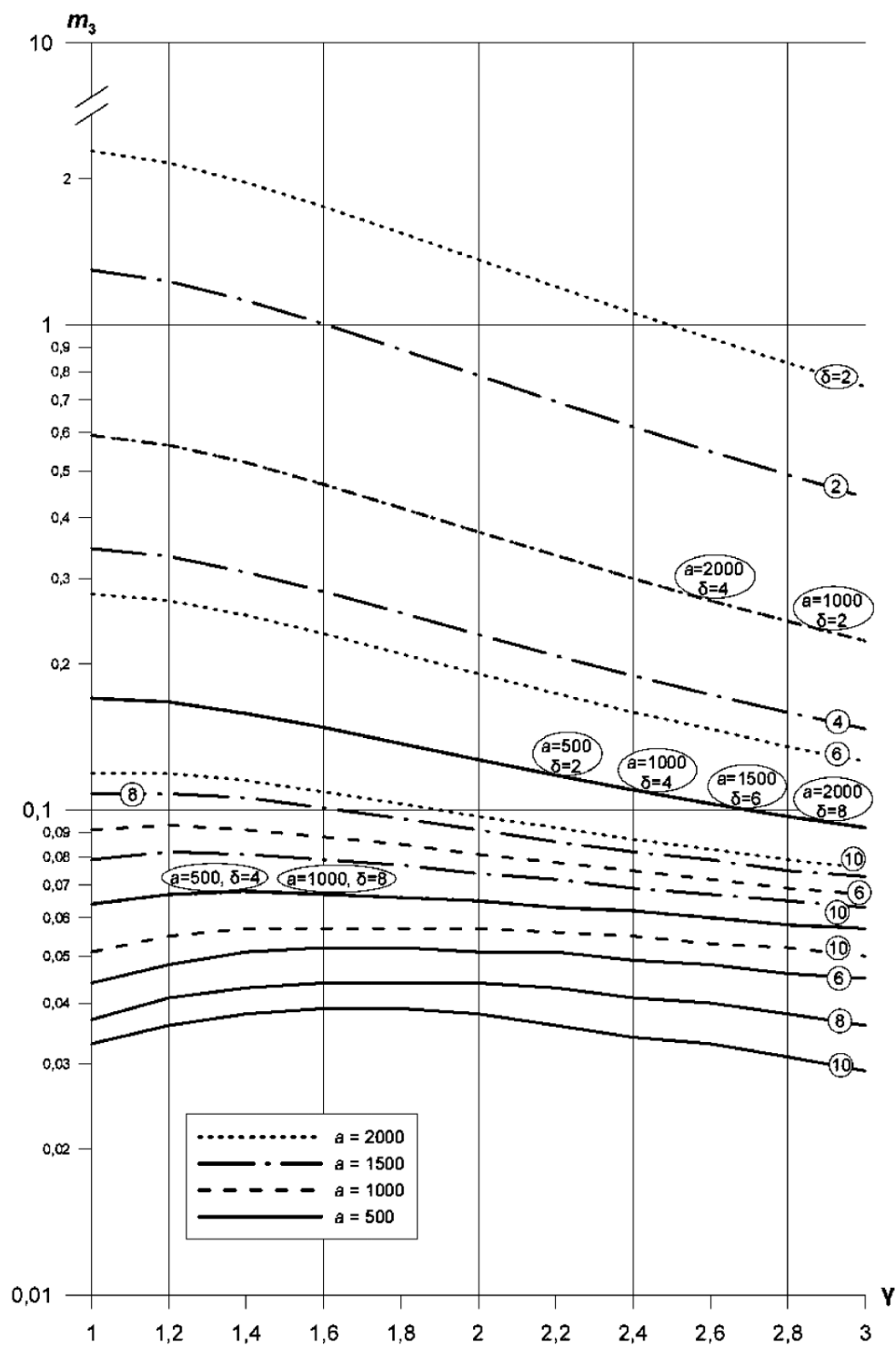
Values of factor  $m_3$  at  $\eta = 100$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_3$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-8

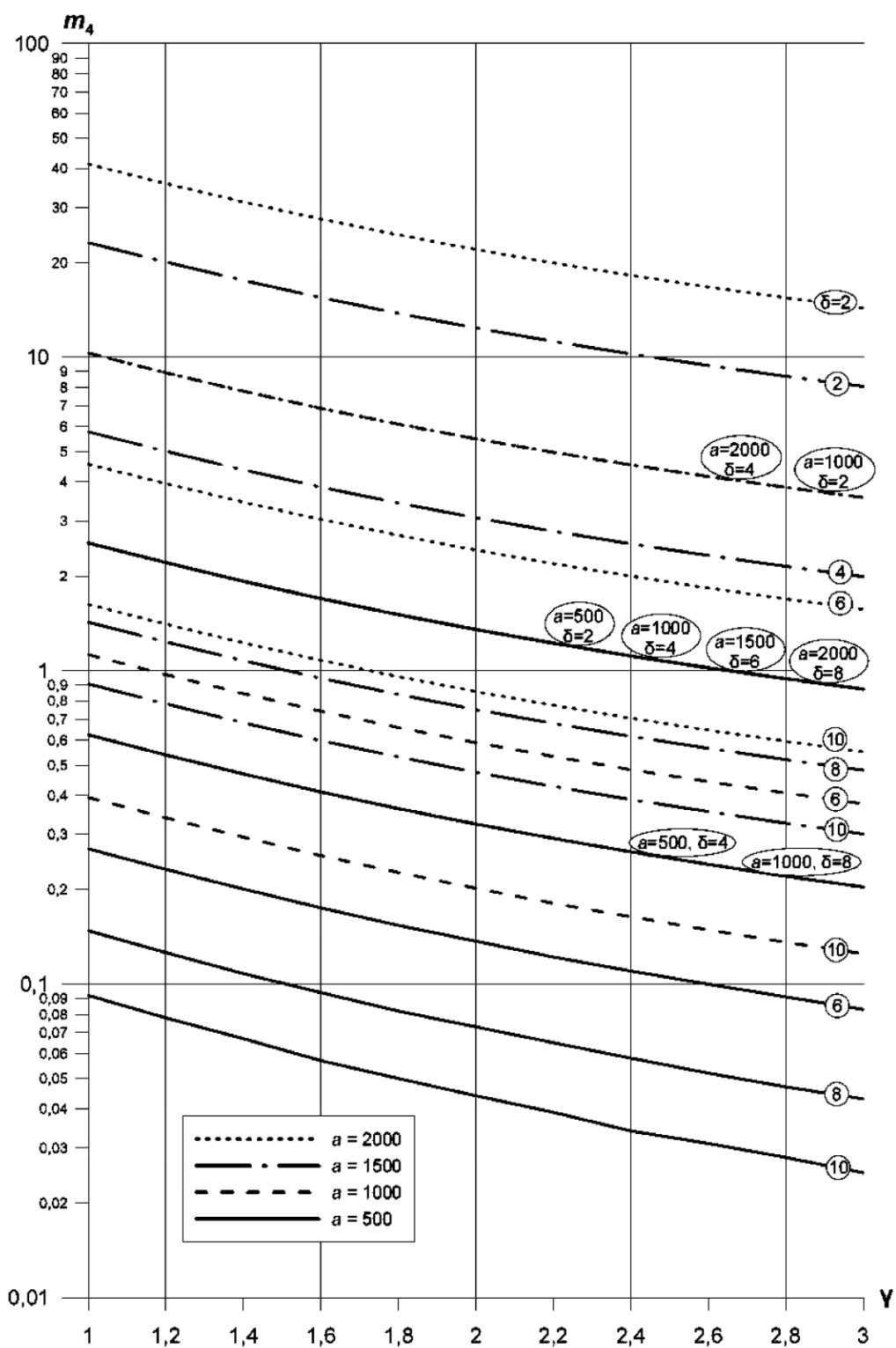
Values of factor  $m_3$  at  $\eta = 400$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_3$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-9

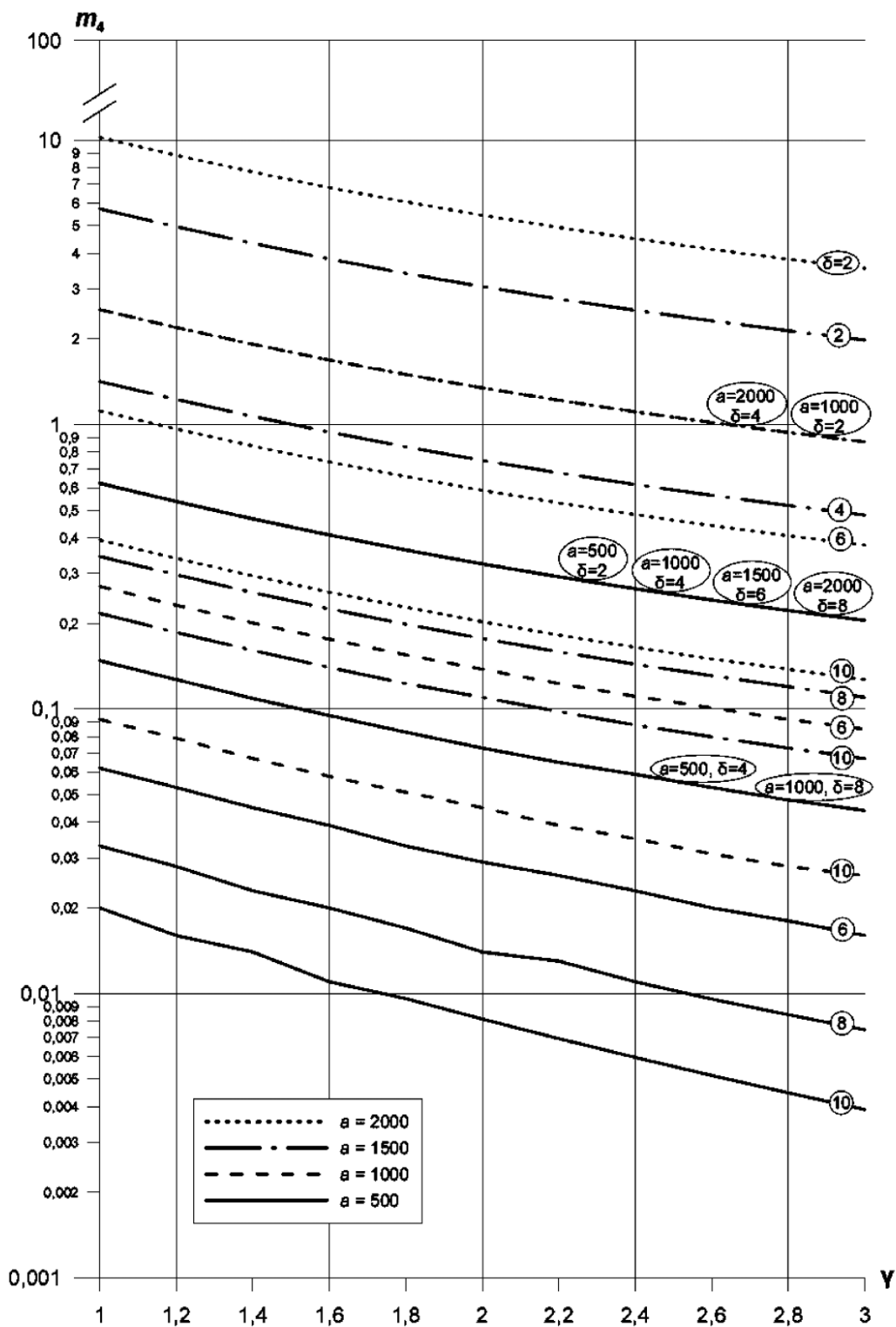
Values of factor  $m_3$  at  $\eta = 800$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_4$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-10

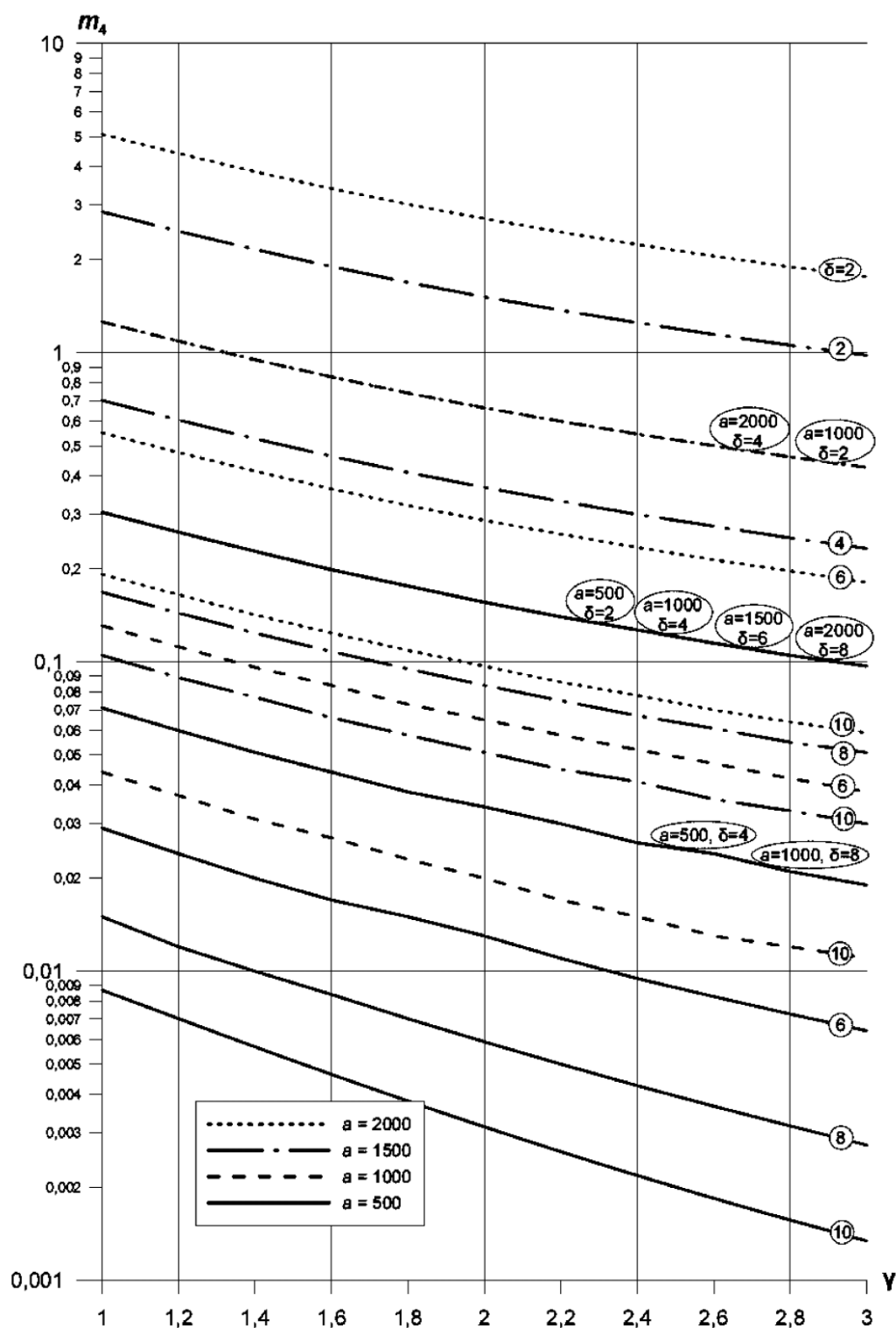
Values of factor  $m_4$  at  $\eta = 100$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_4$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-11

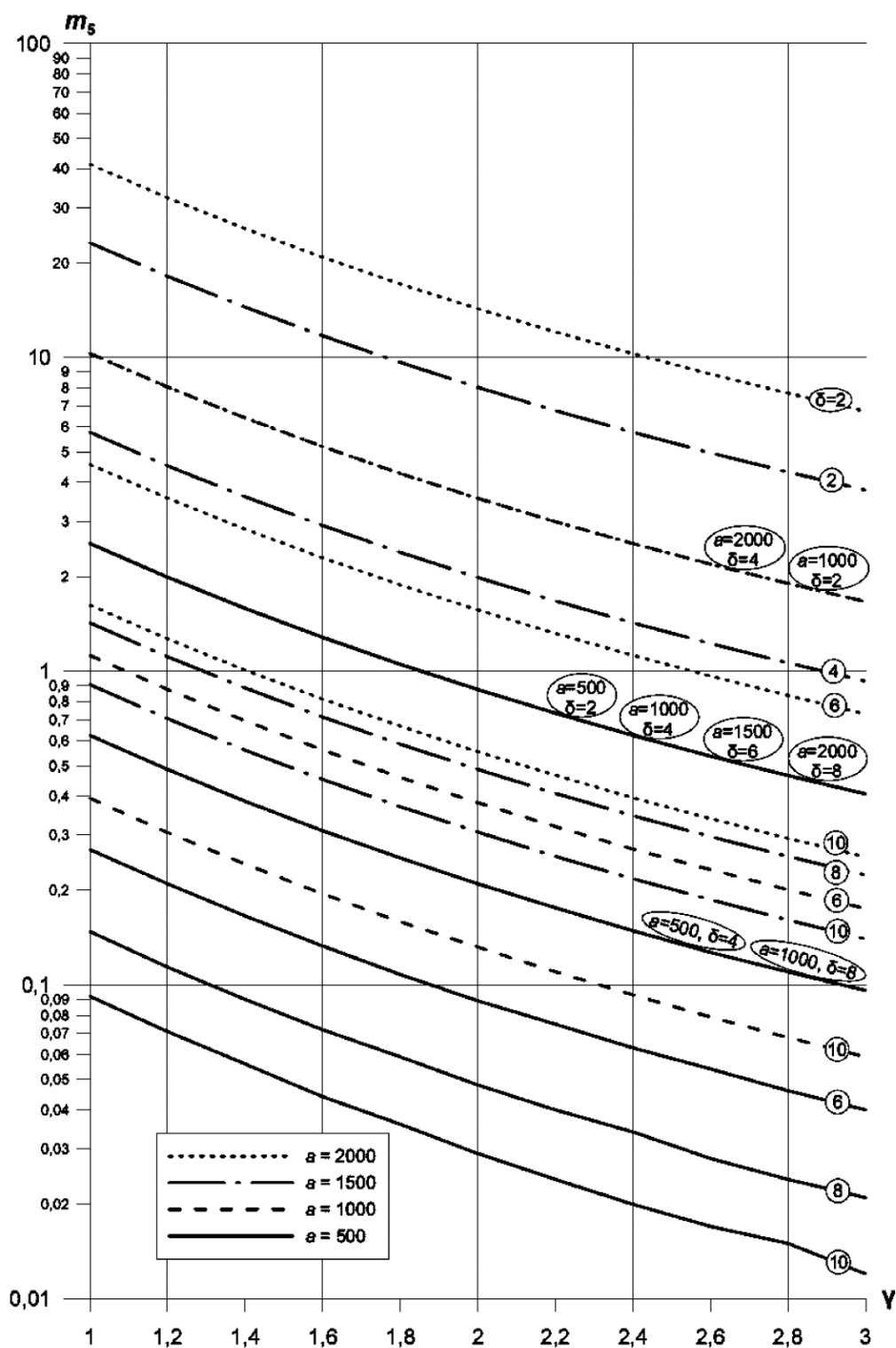
Values of factor  $m_4$  at  $\eta = 400$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_4$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-12

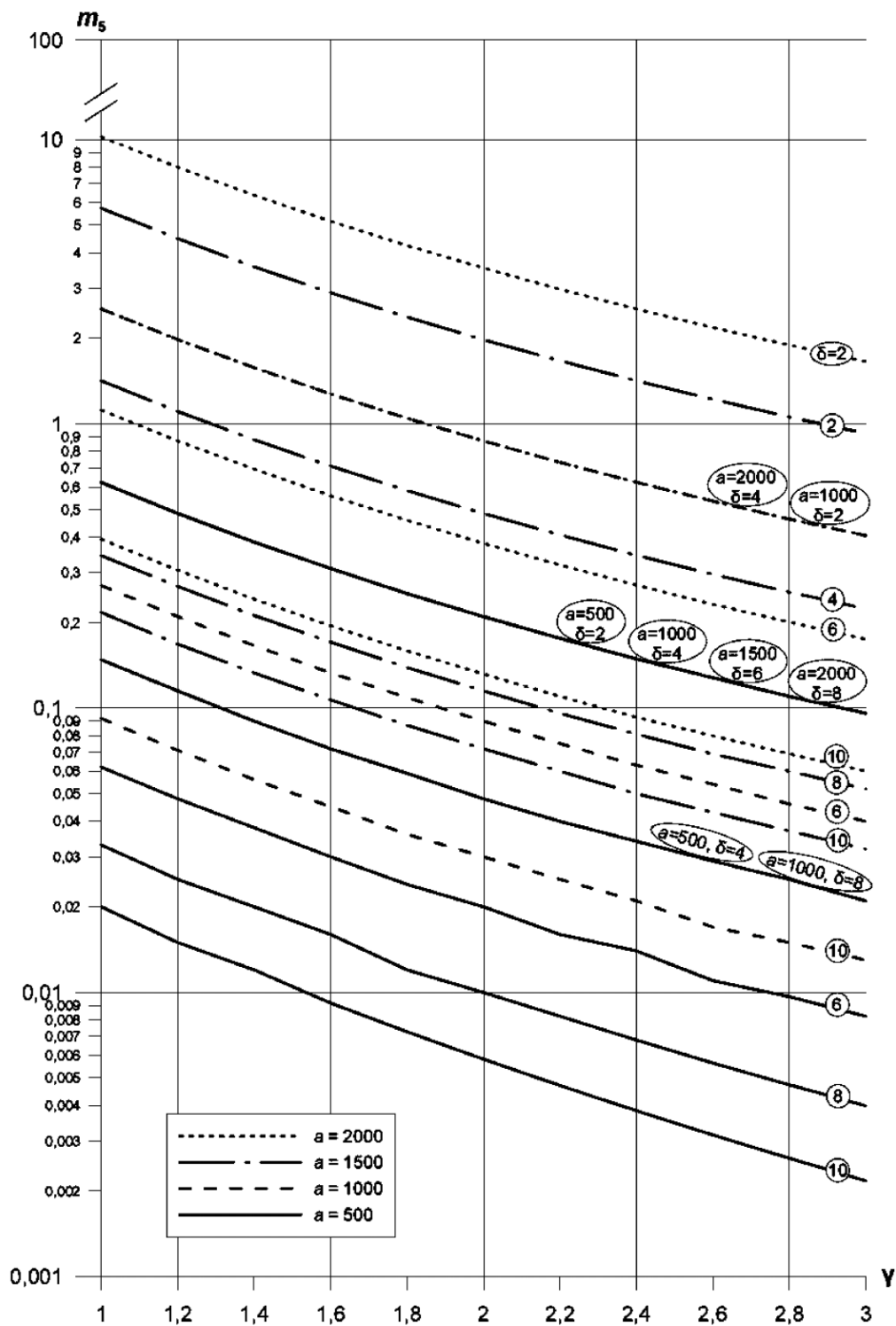
Values of factor  $m_4$  at  $\eta = 800$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_5$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-13

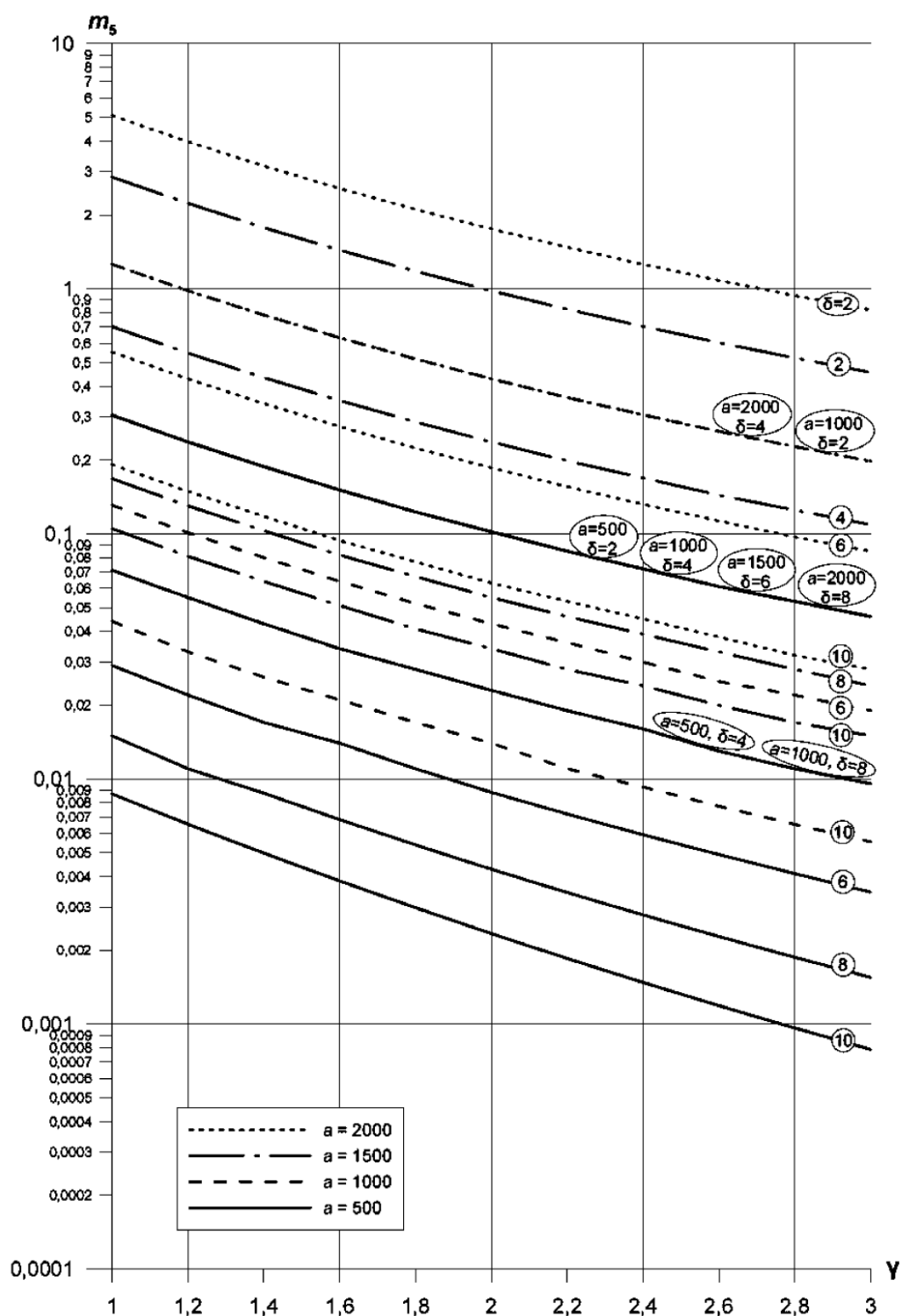
Values of factor  $m_5$  at  $\eta = 100$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_s$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-14

Values of factor  $m_s$  at  $\eta = 400$  for sandwich plates of length  $a$ , in mm



Values of thickness  $\delta$ , in mm, of the sandwich plate load-bearing layer are shown in circles.  
 Values of geometric properties of the sandwich plates for which diagrams of factor  $m_5$  coincide in different combinations of  $a$  and  $\delta$  are shown in ovals

Fig. 8.2-15

Values of factor  $m_5$  at  $\eta = 800$  for sandwich plates of length  $a$ , in mm

### 8.3 Plate edges are fixed along the supporting contour.

The formulae to determine maximum deflections, maximum normal stresses in load-bearing layers for symmetric sandwich plates with same thickness isotropic outer layers are given in 8.4. Transverse deflection of sandwich plate is considered. The load shall be perpendicular to the plate plane.

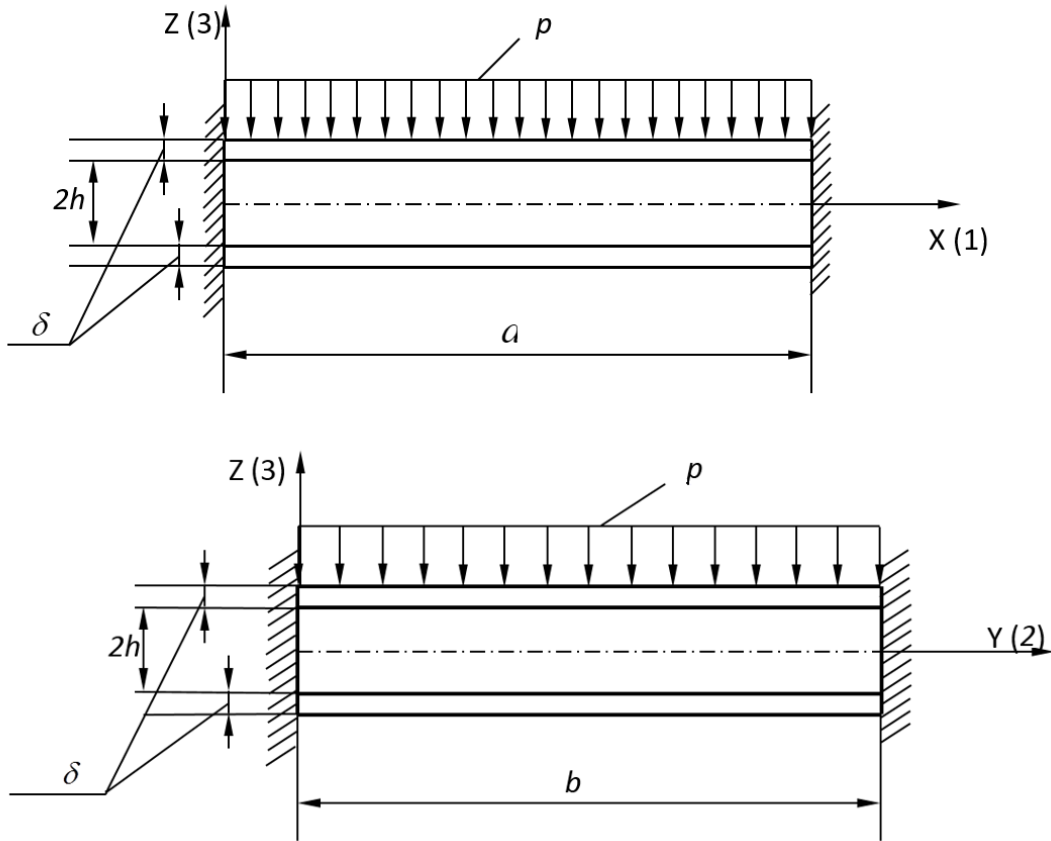


Fig. 8.3

Load type of the sandwich plate

**8.4** Plate deflection, in m, is maximum at  $x = a/2$ ,  $y = b/2$  and determined by the formula

$$|w|_{x=a/2, y=b/2} = \frac{pb^2}{10^3(2h+\delta)} \left[ \frac{m_1 b^2}{E_{bl}\delta(2h+\delta)} + \frac{\bar{m}_1}{G_{core}} \right],$$

where  $a$  = length of the sandwich plate, in m;  
 $b$  = width of the sandwich plate, in m;  
 $2h$  = core thickness of the sandwich plate, in m;  
 $\delta$  = thickness of the load-bearing layer of the sandwich laminate, in m;  
 $p$  = uniformly distributed load, in Pa;  
 $E_{bl}$  = Young's modulus of load-bearing layers of the sandwich plate, in Pa;  
 $G_{core}$  = shear modulus of the core in the sandwich plate, in Pa;  
 $\nu = \nu_{12(bl)}$  = Poisson's ratio of the material of load-bearing layers in the sandwich plate;  
 $m_1, \bar{m}_1$  = factors.

Values of factor  $m_1$  depending on Poisson's ratio  $\nu$  of the load-bearing layers of the sandwich plate and ratio of plate sides  $\gamma = a/b$  are specified in Fig. 8.4-1.

Values of factor  $\bar{m}_1$  depending on ratio of plate sides  $\gamma = a/b$  are specified in Fig. 8.4-2.

Normal stresses  $\sigma_x$ , in Pa, are maximum at  $x = 0$ ;  $a, y = b/2$  and determined by the formula

$$|\sigma_x|_{x=0; a, y=b/2} = p \frac{b^2}{\delta^2 (1+2h/\delta)^2} m_2,$$

where  $m_2$  = factor.

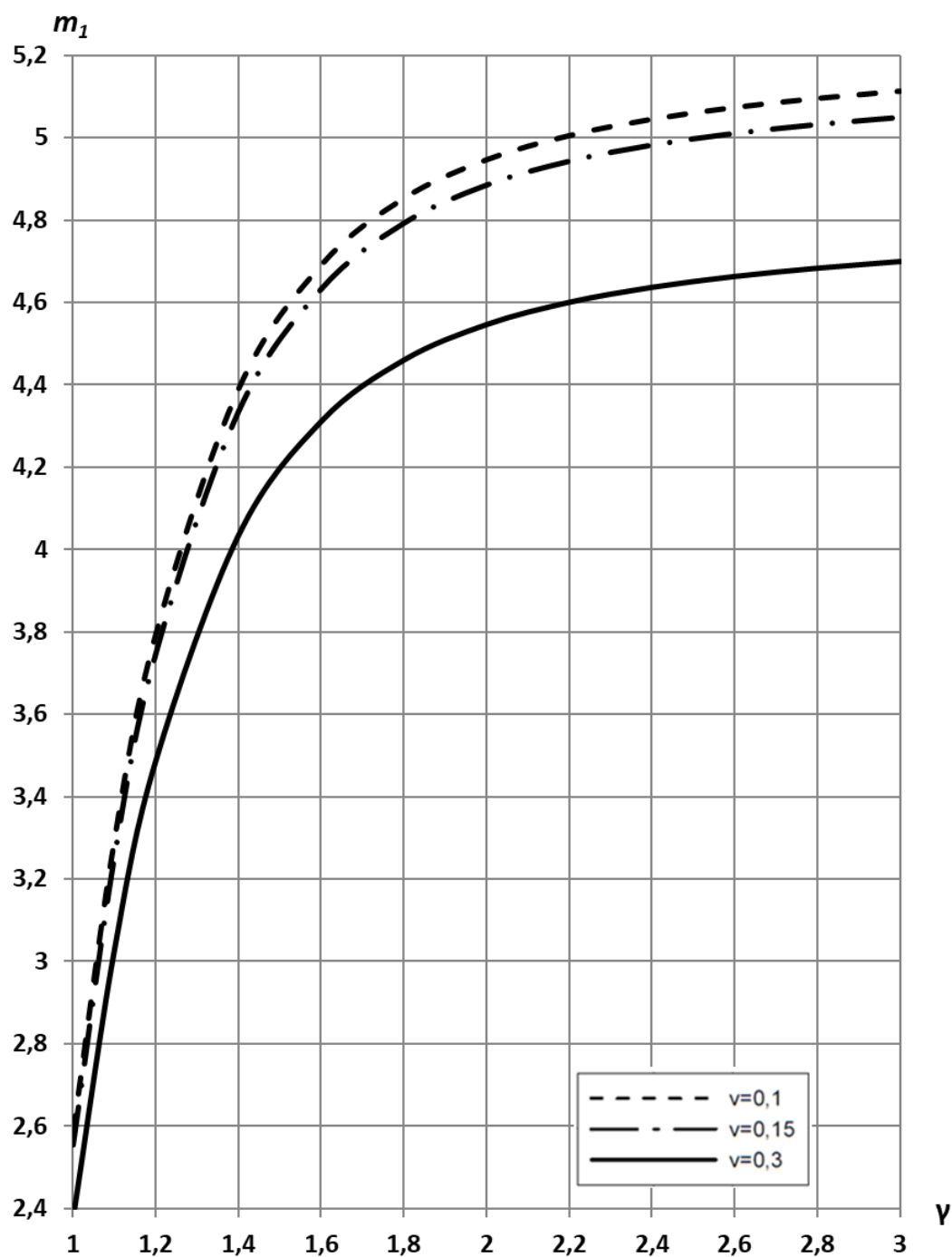


Fig. 8.4-1  
Values of factor  $m_1$

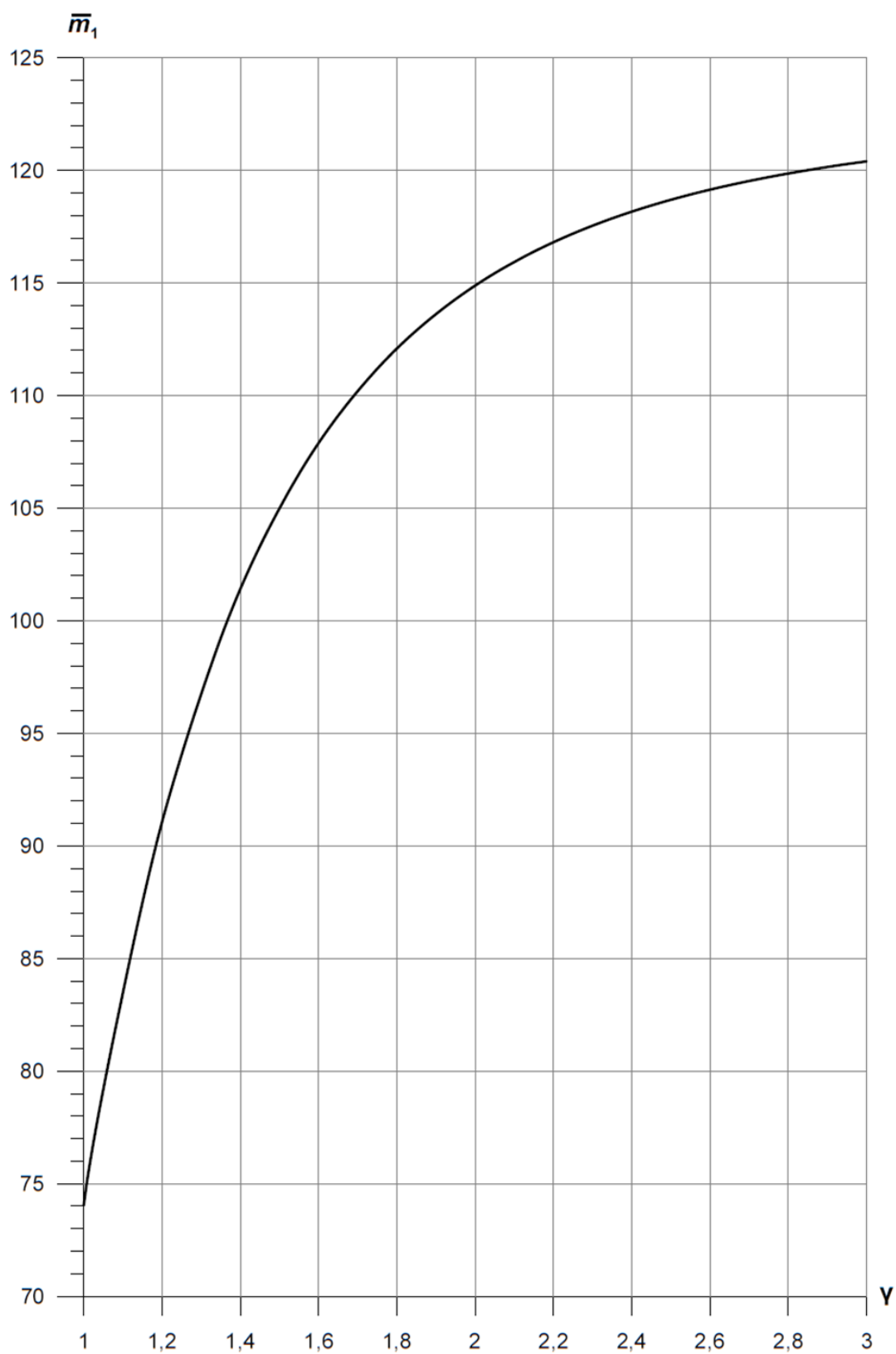


Fig. 8.4-2  
Values of factor  $\bar{m}_1$

Normal stresses  $\sigma_y$ , in Pa, are maximum at  $x = a/2$ ,  $y = 0$ ;  $b$  and determined by the formula

$$|\sigma_y|_{x=a/2, y=0; b} = p \frac{b^2}{\delta^2} \frac{1+h/\delta}{(1+2h/\delta)^2} m_3,$$

where  $m_3$  = factor.

Values of factors  $m_2$  and  $m_3$  depending on Poisson's ratio  $\nu$  of the load-bearing layers of the sandwich plate and ratio of plate sides  $\gamma = a/b$  are specified in [Figs. 8.4-3 — 8.4-4](#) accordingly.

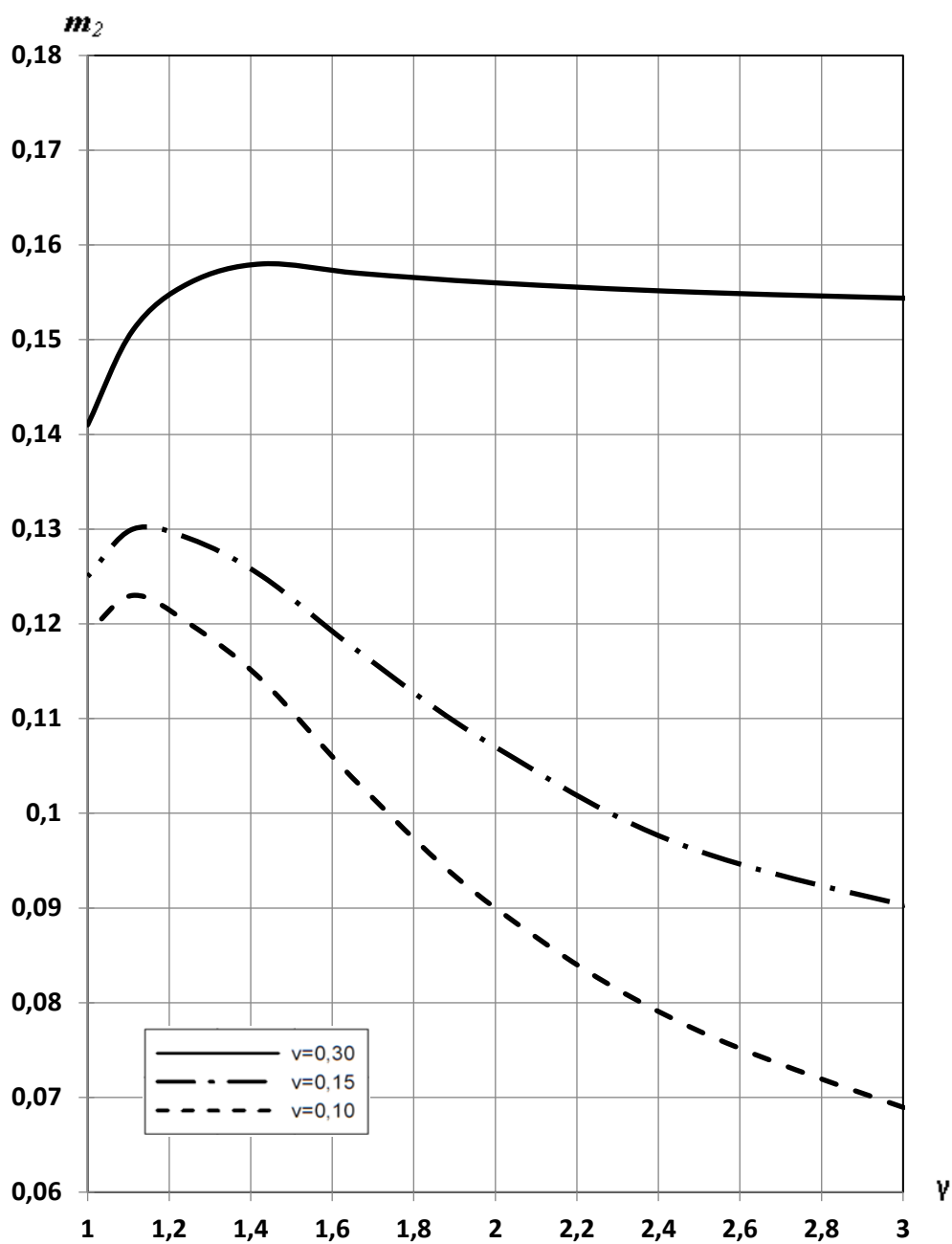


Fig. 8.4-3  
Values of factor  $m_2$

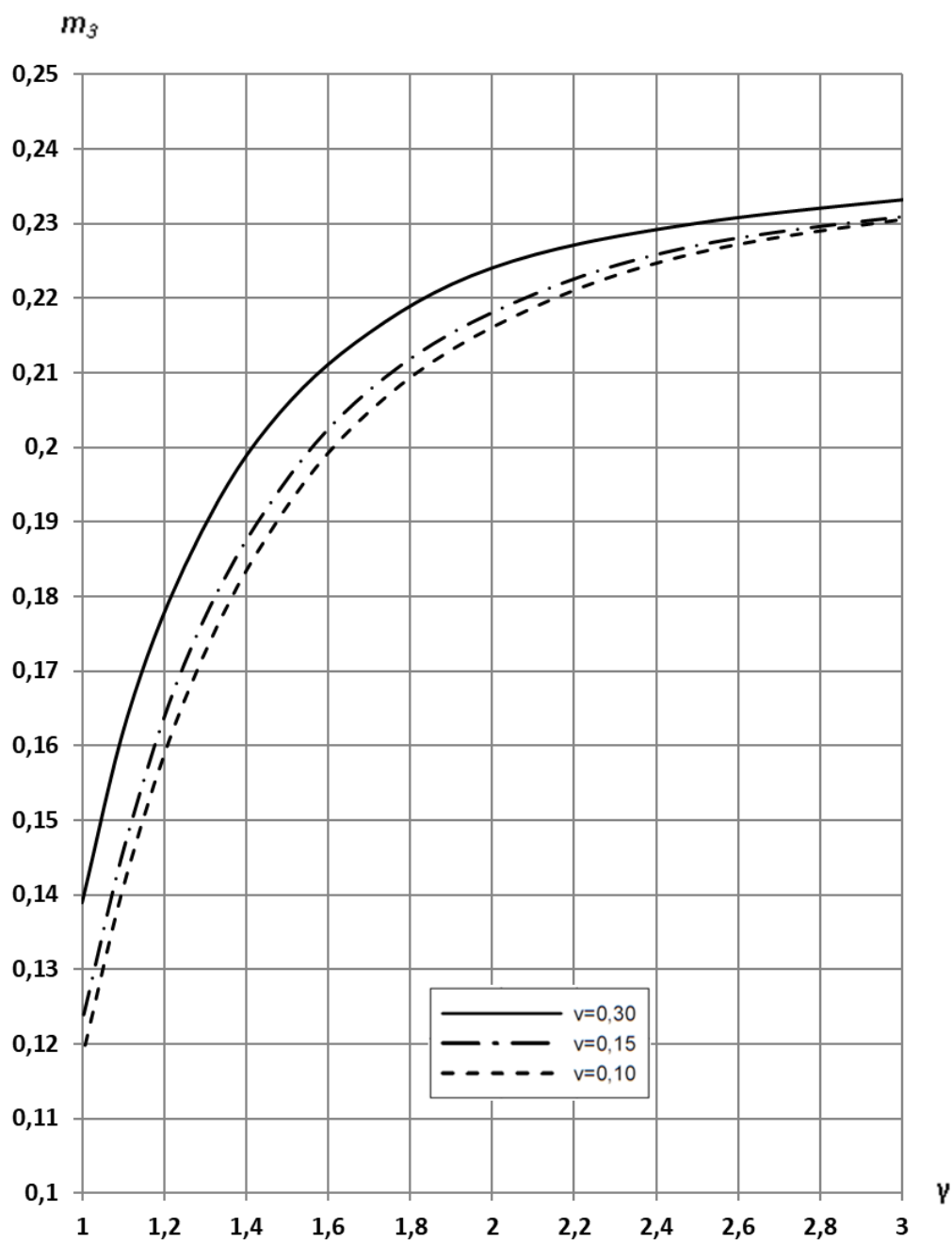


Fig. 8.4-4  
Values of factor  $m_3$

## 9 BUCKLING STRENGTH OF SANDWICH PLATES

**9.1** This procedure is intended for buckling strength calculation of sandwich plates with isotropic core. The procedure allows determining the critical buckling load at one-sided uniform compression, with edges attached in different ways.

The calculation procedure is applied to rectangular symmetric plates over thickness  $\delta_1 = \delta_2 = \delta$ . Load-bearing layers and core are isotropic materials, i.e. for load-bearing layers and the core the following conditions are met accordingly:

$$E_{i(bl1)} = E_{i(bl2)} = E_{bl}; v_{ij(bl1)} = v_{ij(bl2)} = v_{12(bl)};$$

$$E_{i(core)} = E_{core}; G_{ij(core)} = G_{core}; v_{ij(core)} = v_{core}.$$

This procedure may be also used for calculation of stress-strain behavior of sandwich plates with orthotropic load-bearing layers when  $E_{1(bl)} > E_{2(bl)}$  and  $(1 - E_{2(bl)}/E_{1(bl)}) \cdot 100 \% < 20 \%$ , whereas the following conditions for geometric properties and elastic characteristics are met:

$$0,01 \leq \frac{G_{core}}{E_{1(bl)}} \leq 0,1; 0,01 \leq \frac{\delta}{h} \leq 0,25; \frac{2h}{a} \sqrt{1 + (a/b)^2} \leq 0,3.$$

In such case, the core takes up only transverse loads preventing contact between the layers.

**9.2** Ratio of plate sides  $0,5 < a/b < 3$ .

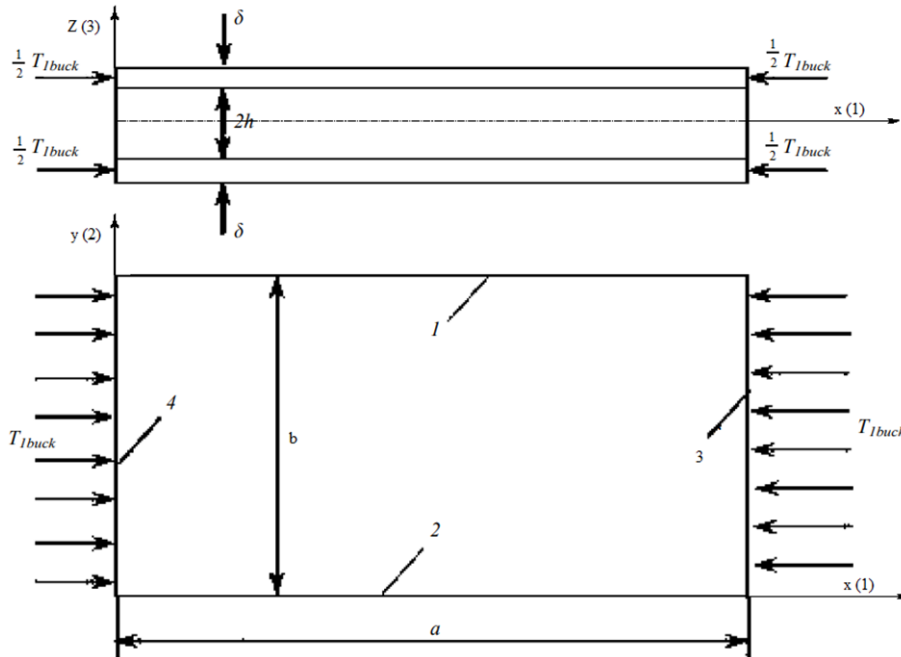


Fig. 9.2  
Load type of a rectangular sandwich plate

**9.3** Buckling load  $T_{1buck}$ , in N/m, is determined by the formula

$$T_{1buck} = m_t \frac{\pi^2 D}{b^2},$$

where  $D = 2D_1 + D_{core} + 2B_1(h + \frac{\delta}{2})^2$ ;

$$D_1 = \frac{E_{bl}\delta^3}{12(1-\nu_{12}^2(bl))};$$

$$B_1 = \frac{E_{bl}\delta}{1-\nu_{12}^2(bl)};$$

$$D_{core} = \frac{2E_{core}h^3}{3(1-\nu_{core}^2)};$$

$E_{bl}$  = Young's modulus of load-bearing layers along the sandwich plate longer side, in Pa;

$E_{core}$  = Young's modulus of the sandwich plate core, in Pa;

$\nu_{12(bl)}$  = Poisson's ratio of the material in load-bearing layers plane in the sandwich plate;

$\nu_{core}$  = Poisson's ratio of the material of the sandwich plate core.

Where  $\frac{h}{\delta} = 5$ , buckling load  $T_{1buck}$ , in N/m, is determined by the formula

$$T_{1buck} = m_t m_m \frac{\pi^2 E_{core} \delta^3}{b^2},$$

where  $m_m = \frac{2}{3} \left[ \frac{91\eta}{1-\nu_{12}^2(bl)} + \frac{125}{(1-\nu_{core}^2)} \right]$ ,  $\eta = \frac{E_{bl}}{E_{core}}$ .

Values of factor  $m_m$  with  $\nu_{12(bl)} = 0,1 \div 0,2$  and  $\nu_{core} = 0,3 \div 0,4$  are determined according to the diagram provided in [Fig. 9.3-1](#).

Values of factor  $m_t$  are determined according to the diagrams depending on the way in which the plate is supported (refer to [Figs. 9.3-2 — 9.3-5](#)), while stiffness characteristics are determined by the formulae specified in this Section.

Value of factor  $k$  for [Figs. 9.3-2 — 9.3-5](#) is determined by the formula

$$k = \frac{\pi^2 B_0 h}{G_{core} b^2},$$

where  $B_0 = 2B_1 + \frac{B_{core}}{3}$ ;

$$B_{core} = \frac{2E_{core}h}{1-\nu_{core}^2};$$

$G_{core}$  = shear modulus of the core in the sandwich plate, in Pa.

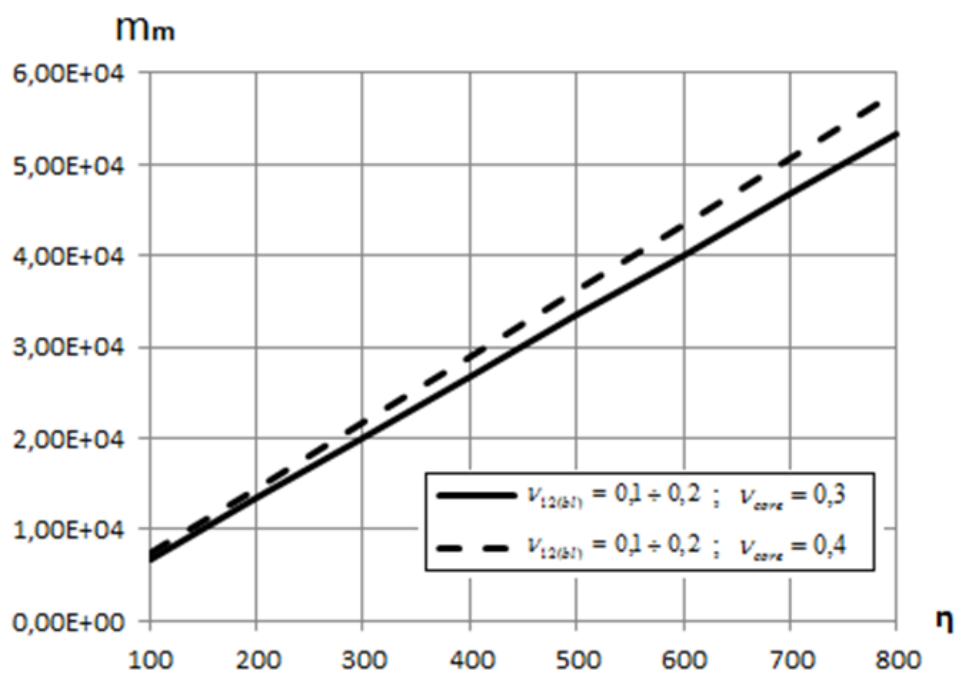


Fig. 9.3-1

Dependency diagram of factor  $m_m$  on ratio of moduli  $\eta$  ( $v_{12(bl)} = 0,1 \div 0,2$  and  $v_{core} = 0,3 \div 0,4$ )

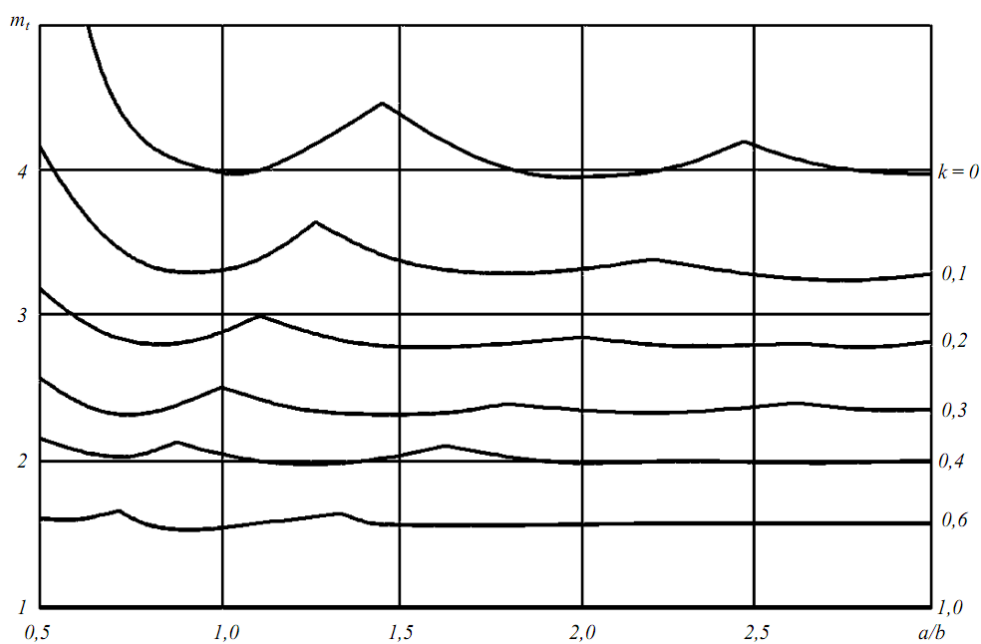


Fig. 9.3-2

Dependency diagram of factor  $m_t$  on ratio of plate sides  $a/b$ , with all edges hinge-supported

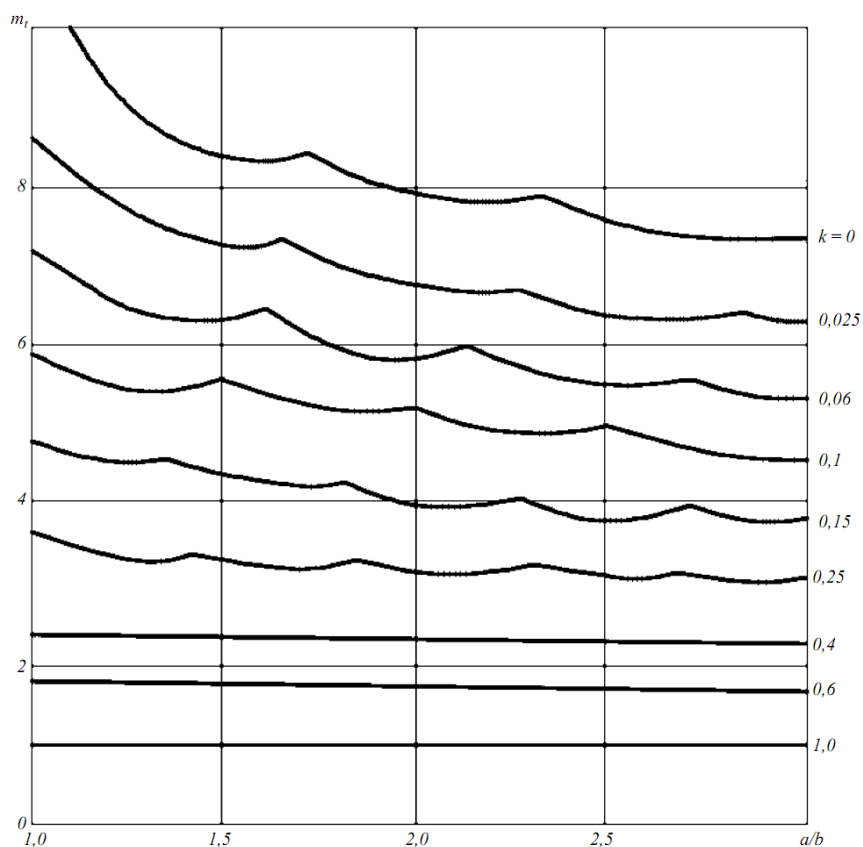


Fig. 9.3-3

Dependency diagram of factor  $m_t$  on ratio of plate sides  $a/b$  with all edges restrained

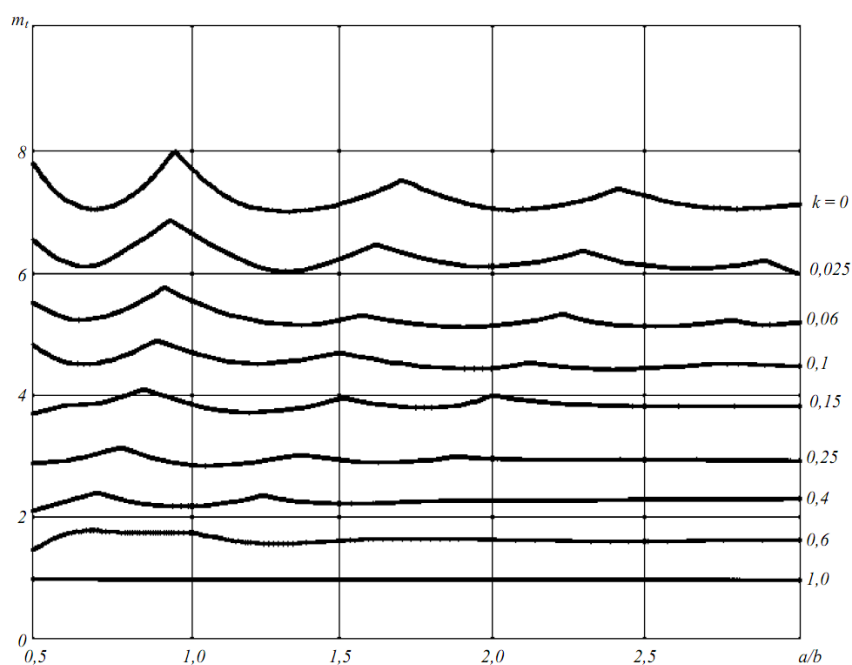


Fig. 9.3-4

Dependency diagram of factor  $m_t$  on ratio of plate sides  $a/b$ , with edges 1, 2 – restrained;  
edges 3, 4 – hinge-supported

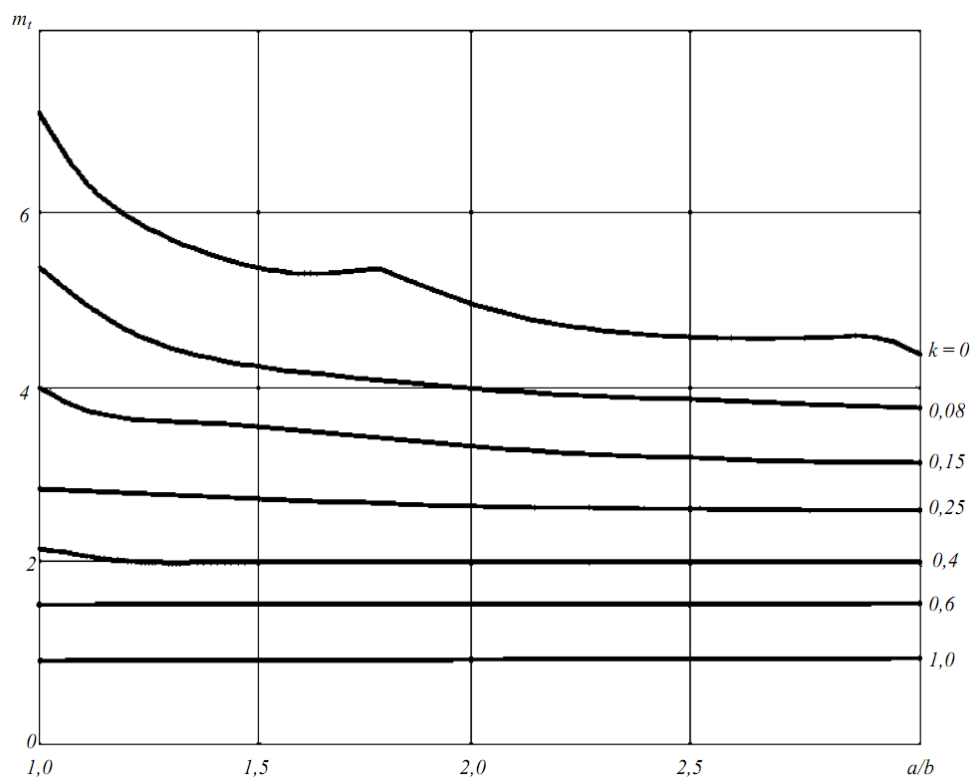


Fig. 9.3-5

Dependency diagram of factor  $m_t$  on ratio of plate sides  $a/b$ , with 1, 2 – hinge-supported; edges 3, 4 – restrained

APPENDIX 2

**STANDARD TEST PROGRAM FOR SAMPLES OF NEW FRPS AND TYPE  
STRUCTURES AND ASSEMBLIES MADE OF THEM**

**1 GENERAL**

**1.1** This Appendix contains the nomenclature and scope of new FRPs not specified in this Part of the Rules for the purpose of their acceptance and approval by RS for their further application in hulls and hull structures.

**1.2** This test program applies to FRPs based on glass, carbon, aramid reinforcement materials as well as polyester, vinylester or epoxy binders.

Tests of FRPs based on other basic components under this test program is allowed upon agreement with the Register.

**1.3** This test program applies to cold- and hot-curing FRPs manufactured by contact moulding, spraying, vacuum injection (infusion technique, RTM techniques), autoclave moulding, pressing, and pultrusion.

Application of other techniques for manufacture of FRPs shall be agreed with the Register.

**1.4** This test program is also applied to lightweight cores used in sandwich (multi-layered) structures. These cores include form plastics (PVC and PUR foams, polyepoxy foams, etc.), and lightweight mats. The above-mentioned cores reinforced with structural elements, and structural orthotropic (non-homogeneous) cores related to structures shall be tested according to special programs approved by the Register.

**1.5** This test program is not applied to adhesion compounds (glues) used for connection of elements of hull structures and products, and to sealant compounds.

Test programs for adhesion and sealant compounds shall be developed by designers of these compounds and shall be approved by the Register.

**1.6** According to this test program, FRPs shall be tested as part of specimens, type structures and assemblies to confirm the possibility of the FRP application and processing technique to hull structures of the ship.

These tests shall be carried out according to the methods of international and/or national standards, and other reference documents upon agreement with the Register.

**1.7** The test program regulates the following:

complete list of new FRP types and check methods, which are mandatory when approved by the Register, and the list of supplementary checks performed upon the request of the Register, designers and other organizations involved in development, acceptance and production launch of the material;

scantlings and manufacturing techniques of laminates (blanks) used for cutting out test specimens;

cutting-out diagram of test specimens from laminates (blanks);

structure and manufacturing procedure of typical structures and assemblies;

test procedures;

procedure for supervision during test procedure;

procedure of processing and recording test results.

**1.8** The relevant procedures specified and regulated by this test program, the scope of testing, their sequence and procedure, as well as the procedure of processing and recording test results are mandatory.

**1.9** The scope of FRP testing as part of specimens, typical structures and assemblies shall ensure complete data on mechanical, process, and other properties of the

material, which are required to confirm possibility of its application as part of structures and products, for which the material is intended.

**1.10** Where the nomenclature and scope of testing under this program are not sufficient to substantiate the assessment of this material application in shipbuilding, or supplementary tests are required to determine special characteristics, development of supplementary test program approved by the Register may be required.

**1.11** Appropriate certified testing equipment and measuring equipment checked (calibrated) in the established order shall be used when carrying out testing under this program.

The testing and measuring equipment used shall be certified and provided with the relevant document confirming certification as well as calibration certificates valid at the date of testing.

## **2 ITEMS UNDER TEST**

**2.1** The following items are subject to testing:  
specimens of FRPs made of monolayers with the use of the same binder and reinforcement material with the same reinforcement scheme;  
specimens of lightweight core;  
type structures made of these FRPs and lightweight core;  
type assemblies made of the same FRPs.

**2.2** The following materials may be used as reinforcement materials for a monolayer of homogeneous FRP (depending on the laying method):  
one-directional tapes;  
woven fabrics of satin, plain, twill, etc. weave types;  
mats;  
multiaxial fabrics (biaxial, triaxial, quadriaxial).

**2.3** Where monolayers of hybrid FRP are made of hybrid reinforcement materials with fibers of different chemical nature, e.g. glass and carbon fibers, may be subjected to testing under this program.

**2.4** Type structures and assemblies are basic design and technology solutions used in hulls and hull superstructures of hulls made of FRPs.

**2.5** Type structures and assemblies are tested to determine whether FRP under question and its processing techniques may be applied for manufacture of hull structures and products, and confirmation of required strength and operability characteristics of FRPs as part of such structures and assemblies.

**2.6** FRPs, type structures and assemblies subject to the RS recognition, including those with the use of the lightweight core shall be manufactured according to the procedure for FRP hulls and superstructures applied at firm (manufacturer), or according to the procedure developed for a particular item.

Where the manufacture procedure or some conditions thereof changed, FRP shall be subjected to retesting in a full or reduced scope, depending on the changes made.

**2.7** Prior to FRP testing, the procedure developed for its manufacture shall be proven at the firm (manufacturer) where specimens, type structures and assemblies are supposed to be manufactured, and process stability and quality control shall be confirmed.

## **3 SCOPE AND TYPES OF TESTS FOR FRPS AND LIGHTWEIGHT CORES**

**3.1** FRPs and lightweight cores subject to the RS recognition shall be tested under this program, as part of specimens, to determine the following characteristics:

physical and mechanical properties in the initial state, considering the operating factors (exposure to sea water, high temperature, cyclic and long-term loads, etc.);  
process characteristics;  
fire risk.

**3.2** Specimens of FRPs and lightweight core are cut out of laminates (blanks) in specified directions and from required areas of these laminates.

Specimens of a lightweight core such as foam plastic are cut out of completed laminates or blocks supplied by the firm (manufacturer).

Laminates (blanks) for cutting out specimens of FRPs and lightweight core based on mats are moulded using the technique developed for manufacture thereof (refer to [2.6](#) and [2.7](#)). Reinforcement schemes of FRP shall be determined in accordance with [2.1](#) and [2.2](#).

**3.3** Laying density of reinforcement materials during moulding of laminates (blanks) shall comply with the requirements for the adopted moulding technique. Percentage of reinforcement materials, depending on their types, for the most common moulding techniques shall be not lower than that specified in [Table 3.1](#).

Table 3.1

**Percentage of reinforcement materials by mass for moulding techniques**

| Moulding technique       | Type of reinforcing material |              |               |               |
|--------------------------|------------------------------|--------------|---------------|---------------|
|                          | Glass mats                   | Fiber glass  | Carbon fibers | Glass roving  |
| Contact moulding         | at least 0,3                 | at least 0,5 | at least 0,35 | –             |
| Closed (vacuum) moulding | –                            | 0,65...0,7   | 0,4...0,6     | –             |
| Spraying                 | –                            | –            | –             | at least 0,35 |

Laying density of reinforcement materials shall vary so that binder percentage at different points of laminates (blanks) differs from its average value by not more than:

for the contact moulding technique – 2 %;

for closed (vacuum) moulding techniques – 0,5 %;

for the spraying technique – 3 %.

**3.4** Quality of laminates (blanks) and cutting of their specimens shall comply with the requirements of this Appendix and/or a standard agreed with the Register.

**3.5** Tests to determine physical and mechanical properties.

**3.5.1** Elastic and strength characteristics of FRPs in the initial state when exposed to short-term loading shall be determined in accordance with the list and test procedures specified in [Table 3.2](#).

**3.5.2** Elastic and strength characteristics of FRPs in the initial condition under repeated static and continuous loading shall be determined in accordance with the list and test procedures specified in [Table 3.3](#).

**3.5.3** Tests of FRP specimens at an elevated temperature of 60 °C shall be carried out to determine the characteristics in items [3–5](#), [8](#), [11](#) of Table 3.2.

Depending on the supposed operation conditions, tests of FRP specimens may be carried out under other values of elevated temperatures.

**3.5.4** Water absorption tests of FRPs shall be carried out in accordance with 2.3.9 of Part XIII "Materials".

Influence of water on FRP resistance is determined from variation of the characteristics specified in items [3–5](#), [7](#), [8](#), [11](#) of Table 3.2. At first, FRP specimens shall be subject to accelerated water exposure according to the procedure provided in 2.3.12 of Part XIII "Materials".

**3.5.5** Lightweight core specimens are tested for water absorption under short-term loading as well to determine elastic and strength characteristics. The list of characteristics to be determined and test procedures are specified in [Table 3.4](#).

**3.5.6** To determine whether FRPs may be applied in specific structures and products, additional characteristics according to [Table 3.5](#) may be considered.

**3.5.7** Depending on operating conditions, the following shall be determined:

impact of oil and petroleum products on mechanical properties;

impact of salt fog on mechanical properties;

linear (volumetric) expansion and thermal conductivity.

**3.5.8** List of additional characteristics may be specified based on the results of tests conducted.

Table 3.2

**List of FRP characteristics determined in the initial state and test procedures under short-term loading**

| Nos. | Characteristic                                     | Test procedure                                                                                                                             | Direction of the test specimens, deg. |
|------|----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|
| 1    | Density                                            | GOST 15139-69<br>ASTM D 792 ASTM D 1505 ISO 1183<br>NF T 57-102                                                                            | —                                     |
| 2    | Binder percentage                                  | GOST 32652<br>ISO 1172<br>ASTM D 792<br>ASTM D 2734 ASTM D 3171<br>SACMA RM 10                                                             | —                                     |
| 3    | Young's modulus                                    | ASTM D 638 (Type 1)<br>ASTM D 3039/D 3039M                                                                                                 | 0°<br>45°<br>90°                      |
| 4    | Shear modulus in the reinforcement plane           | ASTM D 3518<br>ASTM D 4255                                                                                                                 | 0°<br>45°<br>90°                      |
| 5    | Interlaminar shear modulus <sup>1</sup>            | ASTM D 2344<br>ASTM D 2733<br>SACMA SRM 8R                                                                                                 | 0°<br>45°<br>90°                      |
| 6    | Poisson's ratio and tensile elongation             | ASTM D 3039/D 3039M<br>ASTM D 638 (Type 1)                                                                                                 | 0°<br>45°<br>90°                      |
| 7    | Tensile strength at break                          | ASTM C 393/C 393M<br>ASTM D 638/D 638M<br>ASTM D 3039/D 3039M ASTM D 54502<br>NF T 57-101<br>ISO 527<br>ISO 3268<br>SACMA RM4<br>SACMA RM9 | 0°<br>45°<br>90°                      |
| 8    | Compression strength at break                      | ASTM D 638 ASTM D 695<br>ASTM D 3410 ASTM D 5449<br>ASTM D 5467<br>ASTM D 6484/D 6484M ISO 527<br>SACMA RM 1<br>SACMA RM 6                 | 0°<br>45°<br>90°                      |
| 9    | Flexural breaking strength <sup>1</sup>            | GOST 4648-71<br>GOST 25.604-82<br>ASTM C 393/C393M <sup>2</sup><br>ASTM D 790<br>ISO 178<br>ISO 14125<br>NF T 57-105                       | 0°<br>45°<br>90°                      |
| 10   | Shear breaking strength in the reinforcement plane | ASTM C 273<br>ASTM D 3518/D 3518M<br>ASTM D 4255<br>ASTM D 5379<br>ASTM D 5448 ISO 1922<br>SACMA RM 7                                      | —                                     |

| Nos.                                                                                                              | Characteristic                                    | Test procedure                                                                                                            | Direction of the test specimens, deg. |
|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|---------------------------------------|
| 11                                                                                                                | Interlaminar shear strength at break <sup>1</sup> | ASTM D 2344<br>ASTM D 2733<br>ASTM D 5379/D 5379 M-12 <sup>2</sup><br>ASTM E 143<br>ISO 4585<br>NF T 57-104<br>SACMA RM 8 | 0°<br>45°<br>90°                      |
| <sup>1</sup> FRP characteristics at an angle of 45° are determined based on biaxial diagonal fabrics (+45°/-45°). |                                                   |                                                                                                                           |                                       |
| <sup>2</sup> Applied to FRP one-directional reinforcement scheme.                                                 |                                                   |                                                                                                                           |                                       |

Table 3.3

**List of FRP characteristics determined in the initial state and test procedures under repeated permanent and continuous loading**

| Nos.                                                       | Characteristic                                                               | Test procedure                                   | Direction of test specimens, deg. |
|------------------------------------------------------------|------------------------------------------------------------------------------|--------------------------------------------------|-----------------------------------|
| 1                                                          | Endurance limit tensile strength at $2 \times 10^6$ cycles <sup>1</sup>      | ASTM D 3479<br>ISO 527                           | 0°<br>45°                         |
| 2                                                          | Endurance limit in compression at $2 \times 10^6$ cycles <sup>1</sup>        | GOST 33845<br>ISO 13003<br>ISO 527               | 0°<br>45°                         |
| 3                                                          | Bending endurance limit at $2 \times 10^6$ cycles <sup>1</sup>               | GOST 33845<br>ISO 13003 ISO 14125<br>ASTM D 7774 | 0°<br>45°                         |
| 4                                                          | Endurance limit at interlaminar shear at $2 \times 10^6$ cycles <sup>1</sup> | GOST 33845<br>ISO 13003 ISO 14130                | 0°<br>45°                         |
| 5                                                          | Creep rupture tensile strength at $10^3$ h <sup>1</sup>                      | GOST R 57714<br>ASTM D 2990                      | 0°<br>45°                         |
| <sup>1</sup> Refer to <a href="#">Note 1</a> to Table 3.2. |                                                                              |                                                  |                                   |

Table 3.4

**List of lightweight core characteristics to be estimated<sup>1</sup> and test procedures**

| Nos. | Characteristic                | Test procedure                                                                              |
|------|-------------------------------|---------------------------------------------------------------------------------------------|
| 1    | Ultimate water absorption     | GOST 20869-75<br>ISO 2896                                                                   |
| 2    | Young's modulus               | GOST 18336-73<br>GOST 17370-712<br>ASTM E1875-13<br>ASTM D 1621<br>ASTM D 1623 <sup>2</sup> |
| 3    | Shear modulus                 | ASTM C 273                                                                                  |
| 4    | Tensile strength at break     | GOST 17370-71<br>ASTM D 1623                                                                |
| 5    | Compression strength at break | GOST 23206-78<br>ASTM D 1621                                                                |
| 6    | Shear breaking strength       | ASTM C 273<br>ASTM C393/C393M                                                               |

<sup>1</sup> Elastic and strength characteristics of the lightweight core based on mats shall be determined in 0° and 90° directions in the mat laying plane, with 0° direction positioned along the mat fabric.

<sup>2</sup> These standards determine the technique of tensile test of specimens without specifying the technique of Young's modulus determination.

Table 3.5

**List of additional characteristics of polymer composites and their estimation techniques**

| Nos. | Characteristic                                                 | Test procedure                                                                                       |
|------|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| 1    | Ultimate tensile-compression strength in transversal direction | ASTM D 6415<br>ASTM C 297                                                                            |
| 2    | Crack resistance (Modes I and II)                              | ASTM D 5528-01 (Mode I), Method of bending a framing member with a notch on one side (ENF) (Mode II) |
| 3    | Charpy's impact strength                                       | GOST 4647-80<br>ISO 179                                                                              |
| 4    | Tension-compression creep                                      | GOST R 57714<br>ASTM D 2990                                                                          |

**3.6 Tests to determine technological properties.**

**3.6.1** Tests to determine process characteristics are carried out to determine the workability, i.e. the ability of basic components – reinforcement materials and binder to be processed in a structure (product) made of FRPs by means of the selected manufacture technique (contact moulding, spraying, vacuum injection (injection technique, RTM techniques), autoclave moulding, pressing, pultrusion), with stability and proper quality performance ensured.

**3.6.2** To determine workability of basic components, the following characteristics shall be determined:

- binder viscosity;
- temperature of exothermic reaction during binder polymerization;
- extent and time of binder polymerization;
- amount of binder shrinkage upon its polymerization;
- impregnability and resin-saturation of the reinforcement material;
- binder percentage in FRPs;
- permissible thickness of FRPs in case of continuous moulding;
- maximum temperature and time of FRP heat treatment by hot curing;
- amount of thixotropic agents and ability to mold vertical surfaces.

**3.6.3** Dynamic viscosity is determined according to the procedure of ASTM D2196-05 or GOST 1929-87.

**3.6.4** Temperature of exothermic reaction during binder polymerization is determined according to GOST 21970-76 (ISO 584).

**3.6.5** Extent and time of binder polymerization are dependent on the glass transition temperature as per ISO 11357, time of binder polymerization (gel time) – GOST 22181-91 (ISO 2535).

**3.6.6** Binder shrinkage upon its polymerization is determined according to GOST 18616-80 and ISO 2577.

**3.6.7** Impregnability and resin-saturation of the reinforcement material (determination of impregnation speed for comparative testing) and resin-saturation are determined according to the procedures specified in [item 2](#) of Table 3.2.

**3.6.8** Binder percentage in FRPs is determined according to the procedures specified in [item 2](#) of Table 3.2.

**4 SCOPE AND TYPES OF TESTS OF TYPE STRUCTURES AND ASSEMBLIES**

**4.1** Type structures and assemblies shall represent basic members and elements of hull structures, have representative scantlings and allow manufacturing with the use of the selected technique to confirm that this technique may be applied for manufacturing hull structures and ensures process stability and proper quality performance.

**4.2** Type structures and assemblies shall be made of the FRP subject to recognition, including that using the lightweight core, by the technique adopted considering [2.6](#).

Type structures and assemblies may be used in FRPs based on other reinforcement materials of the chemical nature similar to that subject to recognition, and on the same binder. In such case, these FRPs shall be recognized or may undergo the recognition procedure together with the first FRP.

**4.3** Type structures and assemblies shall be manufactured in accordance with lists of construction and production documentation sets.

**4.4** In this program, type structures and assemblies comprise:

single-skin laminates;  
sandwich laminates;  
closed box section framing member;  
butt joint assembly;  
T-joint assembly.

**4.5** Single-skin laminates and their test procedure.

**4.5.1** Single-skin laminates are made of the FRP under consideration, of the specified reinforcement scheme (refer to [2.1](#) and [2.2](#)), with the reinforcement material fabric laid along the longer side of the laminate.

**4.5.2** Laminates are made by the adopted technique ([refer to 2.6](#)) in two positions — horizontal and vertical, one laminate per position ([refer to Fig. 1](#)). In the first position, a laminate shall not be smaller than 1500×1000 mm, in the second position — not smaller than 2000×1000 mm, with the longer side positioned vertically. In both cases, the laminate thickness shall be equal to 10 mm.

During manufacture of a vertical laminate, amounts of thixotropic agents and glue (to secure dry reinforcement material when the vacuum injection technique is used) shall be strictly limited.

**4.5.3** From laminates in three different regions (near shorter sides and in the middle) prismatic specimens are cut out ([refer to Fig. 2](#)):

for static bending test as per GOST 4648-71, GOST 25.604-79 (dimensions 200×20 mm), 10 pcs per reinforcement direction;

for interlaminar shear test — dimensions 60×10 mm, 10 pcs per reinforcement direction;

for determination of density as per GOST 15139-69;

for determination of binder percentage according to the procedures specified in [item 2](#) of [Table 3.2](#).

**4.5.4** Half of specimens for bending tests (according to a three-point bending scheme) and interlaminar shear tests shall be tested under short-term loading, the other half — under repeated static loading as per standard recognized by the Register, at  $10^4$  cycles of 50 % loading level of the average breaking load determined from static test results. Where the specimen has not failed as a result of repeated static tests, it shall be tested under short-term loading until failure occurs.

**4.6** Sandwich laminates and their test procedure.

**4.6.1** In sandwich laminates load-bearing layers are made of the RS recognized FRP of the specified reinforcement scheme (refer to [2.1](#) and [2.2](#)), with the reinforcement material fabric laid along the longer side of the laminate. The lightweight core, or the core which has been already recognized and provided with the Type Approval Certificate (CTO) shall be used as the core. Where polyvinylchloride foam of PVC type or PUR foam is used, its density shall be 100 – 150 kg/m<sup>3</sup>.

**4.6.2** Laminates are manufactured similarly to single-skin ones ([refer to 4.5.2](#)). Scantlings of laminates for two moulding positions shall be not less than 2000×1000 mm. In such case, the thickness of loadbearing layers shall be equal to 4 mm, and that of the core — 40 mm.

**4.6.3** From laminates in three different regions (near shorter sides and in the middle) prismatic specimens are cut out ([refer to Fig. 3](#)):

for bending tests as per ASTM D790/ASTM C393/C393M (dimensions 750×650×48 mm), 6 pcs per reinforcement direction;

for short beam test as per ASTM D2344/SACMA SRM 8R (dimensions 300×50×48 mm), 6 pcs per reinforcement direction.

**4.6.4** Half of specimens for bending tests (according to a four-point bending scheme) and short beam tests shall be tested under short-term loading, the other half – under repeated static loading as per the standard or procedure approved by the Register, at  $10^4$  cycles of 50 % loading level of the average breaking load determined from static test results. Where the specimen has not failed as a result of repeated static tests, it shall be tested under short-term loading until failure occurs.

**4.7** Closed box section framing members and their testing procedure.

**4.7.1** Closed box section framing members consist of an effective flange, section's core, its sheathing tapered into flanges, and additional elements such as brackets/knees, brackets and straps mounted for stiffening the section where concentrated loads are applied during bending tests of members ([refer to Fig. 4](#)).

The effective flange and sheathing of the section are made of the tested FRP based on the same reinforcement material of the specified reinforcement scheme ([refer to 2.1](#) and [2.2](#)), except for biaxial diagonal fabrics and mats, or on two tested FRPs of different reinforcement materials. In the latter case, percentage of these FRPs relative to one another shall be specified in the detailed design and construction documentation for manufacture of these members. Polyvinylchloride foam of PVC type or PUR foam of 80 – 150 kg/m<sup>3</sup> density, which shall be recognized by the Register, are used as a core.

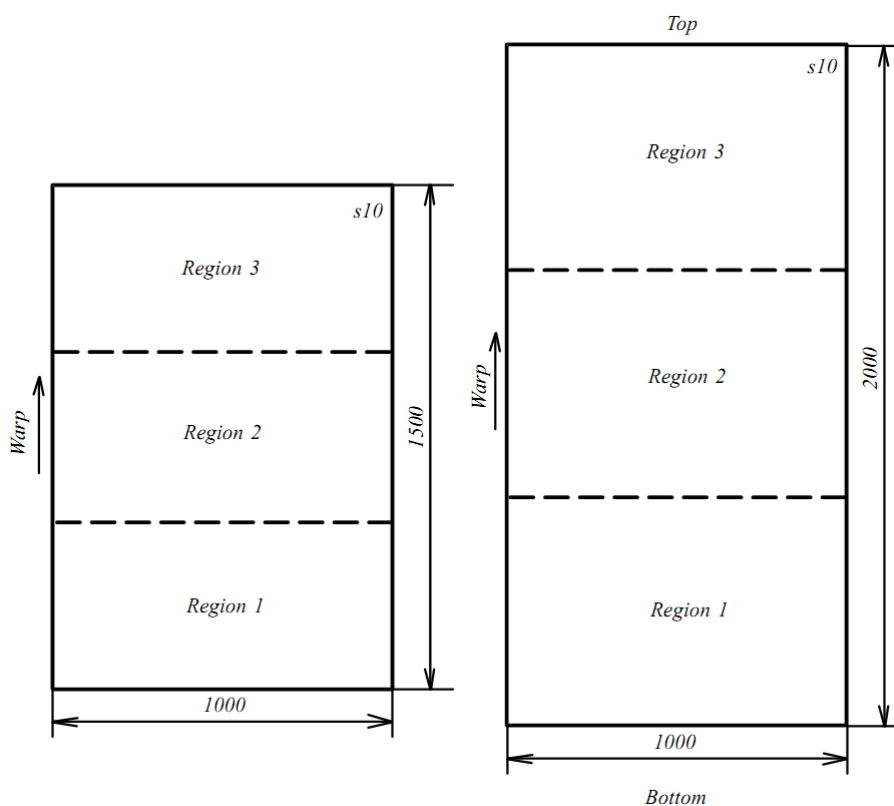


Fig. 1

Single-skin laminates made of FRPs by horizontal (left) and vertical (right) moulding

Members have the core depth of 150 mm and effective flange thickness of 12 mm ([refer to Fig. 4](#)).

**4.7.2** Members are manufactured according to the adopted procedure ([refer to 2.6](#)). In this case, manufacture and matting-in of brackets, matting-on of straps in places of stiffening shall be performed by the contact moulding technique.

**4.7.3** Members shall have the 800 mm length for short beam tests according to a three-point bending scheme, on the 700 mm span, and manufactured according to the procedure approved by the Register. The load shall be applied to members from the effective flange side.

Six members shall be manufactured. Half of members shall be tested under short-term loading until failure, the other half shall be subject to repeated static tests at  $10^4$  cycles, at the maximum load value per cycle equal to 50 % of the average breaking load determined from static test results.

**4.8** Butt joint assembly and its test procedure.

**4.8.1** The butt joint assembly consists of two laminates 10 mm thick connected with two-side straps, without edge preparation ([refer to 5](#)). Laminates and connecting straps shall be made of the certified FRP based on the same reinforcement material, of the specified reinforcement scheme ([refer to 2.1](#) and [2.2](#)), except for biaxial diagonal fabrics and mats.

**4.8.2** Manufacture of laminates and matting-on of connecting straps shall be performed by the adopted procedure of manufacture – either infusion or contact moulding techniques ([refer to 2.6](#)). In such case, depending on the procedure recognized by the Register, laminates may be manufactured using the infusion technique, and connecting straps may be matted on by the contact moulding technique, and vice versa.

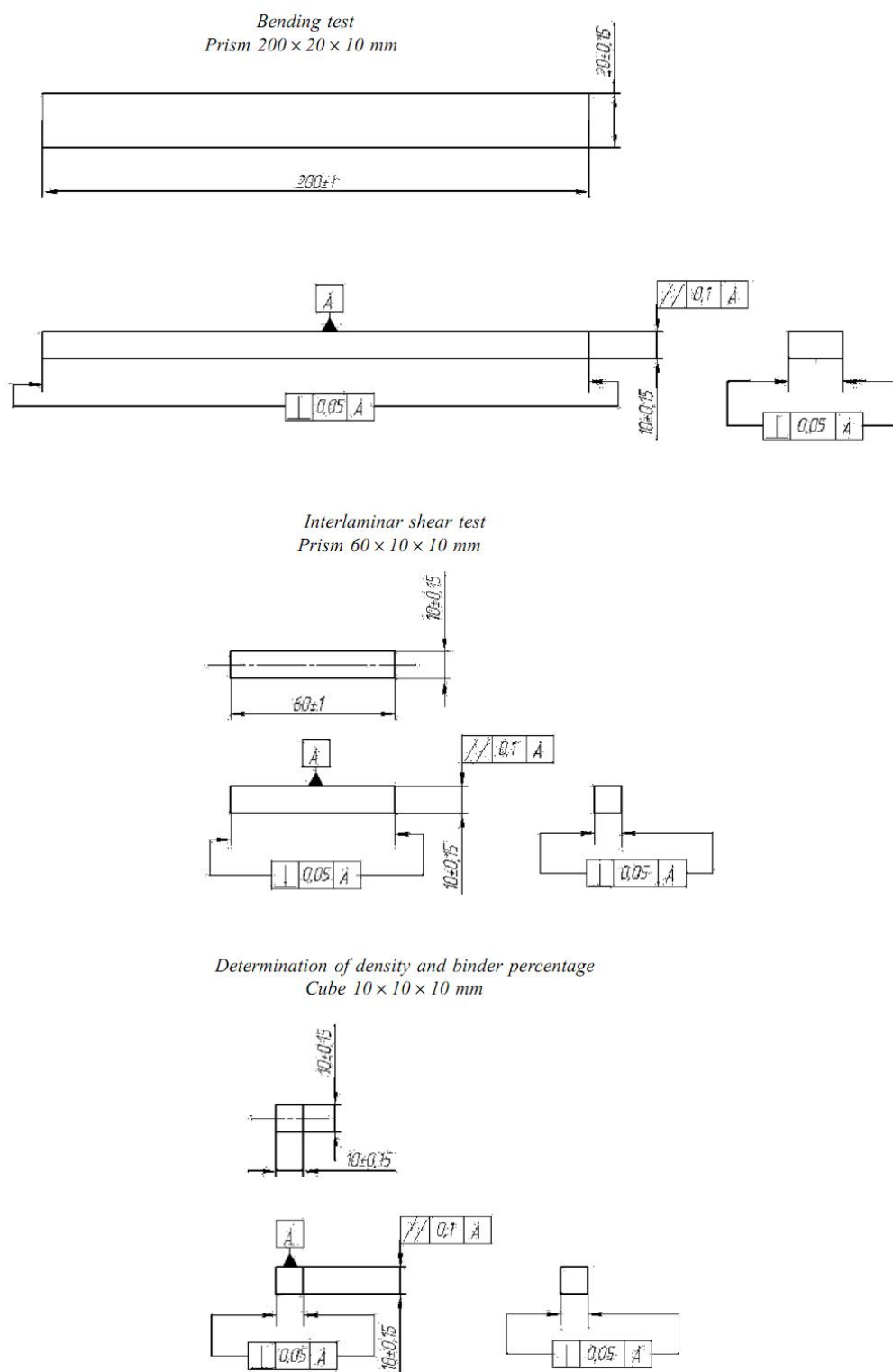


Fig. 2

FRP specimens for physical and mechanical tests in the initial state, cut out from laminates made of horizontal and vertical moulding ([refer to Fig. 1](#))

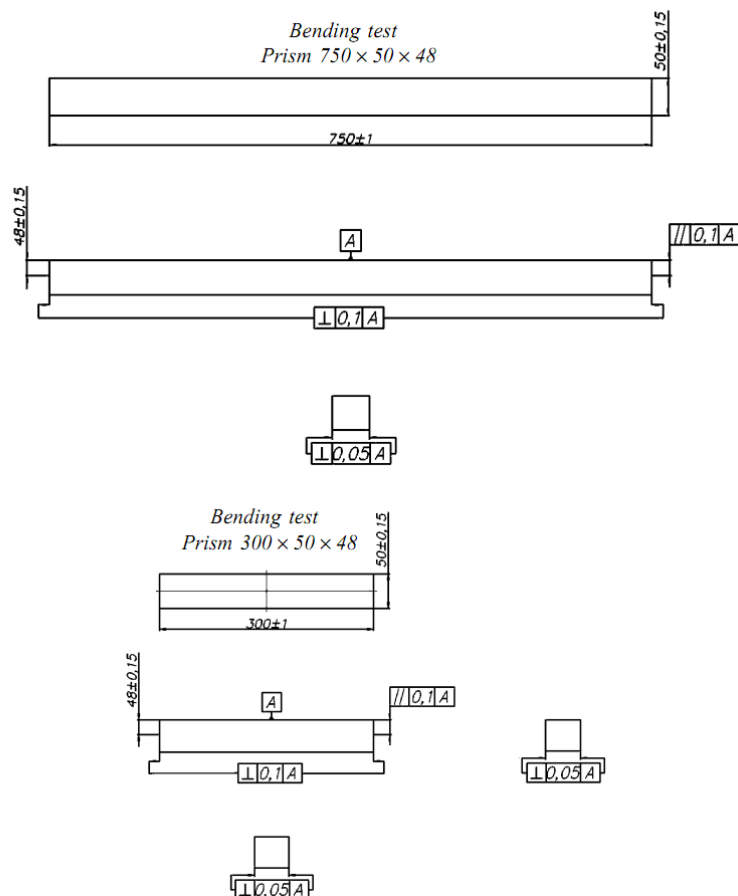


Fig. 3

FRP specimens for physical and mechanical tests in the initial state, cut out from laminates made of horizontal and vertical moulding (refer to [4.6.1](#) and [4.6.2](#))

**4.8.3** Six butt joint assemblies shall be made to perform tensile testing according to the procedure approved by the Register. Half of assembly specimens shall be tested under short-term loading until failure, the other half shall be subject to repeated static tests at  $10^4$  cycles, at the maximum load value per cycle equal to 50 % of the average breaking load determined from static test results. Where the specimen does not fail as a result of repeated static tests, it shall be tested under short-term load until failure to determine the residual strength.

**4.9** T-joint assembly and its test procedure.

**4.9.1** T-joint assembly consists of two laminates 10 mm thick connected with moulding-in angles (refer to Fig. 6). Laminates and moulding-in angles shall be made of the tested FRP based on the same reinforcement material, of the specified reinforcement scheme (refer to [2.1](#) and [2.2](#)), except for biaxial diagonal fabrics and mats.

**4.9.2** Selection of a laminate manufacture technique and moulding-in of angles shall be performed similarly to the procedure for butt joint assembly (refer to [4.8.2](#)).

**4.9.3** Six T-joint assemblies shall be made for the purpose of uniform separation test according to the procedure approved by the Register (refer to Fig. 6). Half of specimens shall be tested under short-term loading until failure, the other half shall be subject to repeated static tests at  $10^4$  cycles, at the maximum load value per cycle equaling to 50 % of the average breaking load determined from static test results. Where the specimen has not failed as a result of repeated static tests, it shall be tested under short-term load until failure to determine the residual strength.

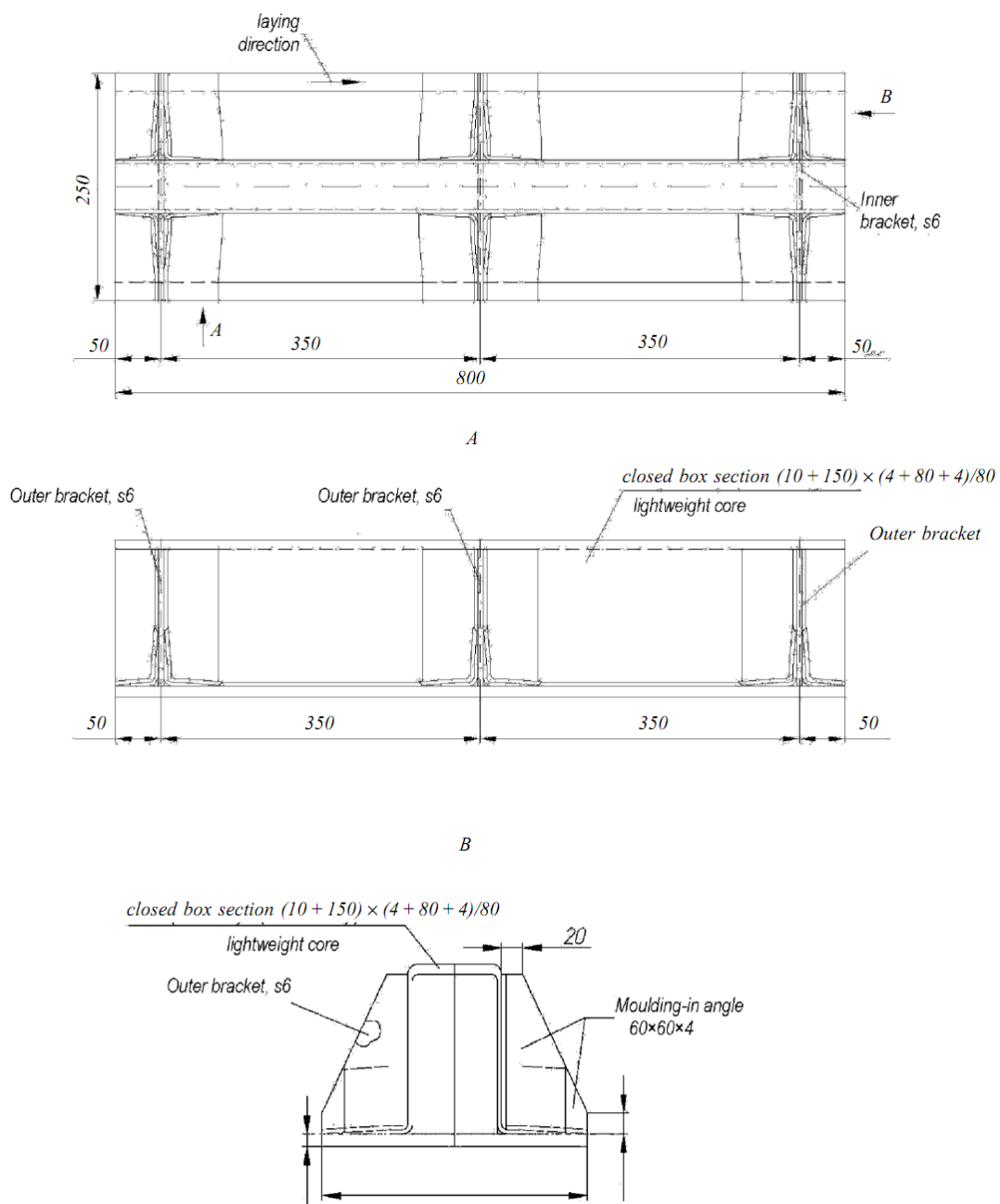


Fig. 4

General view of the closed box section framing members for short beam tests  
 10 – face plate thickness, in mm; 150 – depth of lightweight core, in mm; 4 – thickness of section's sheathing webs, in mm; 80 – core width, in mm; 80 as a denominator – core density, in kg/m<sup>3</sup>

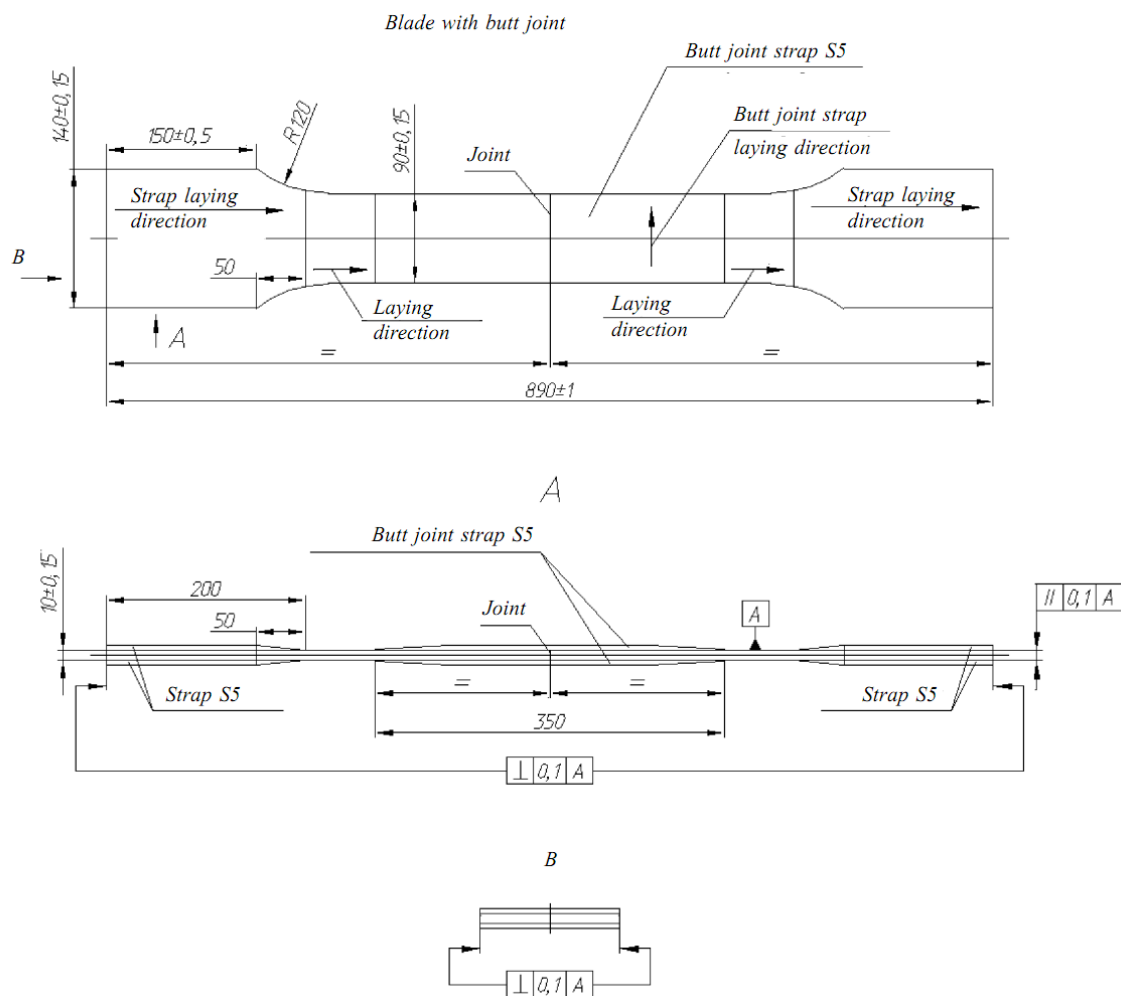


Fig. 5  
Butt joint assembly for tensile testing

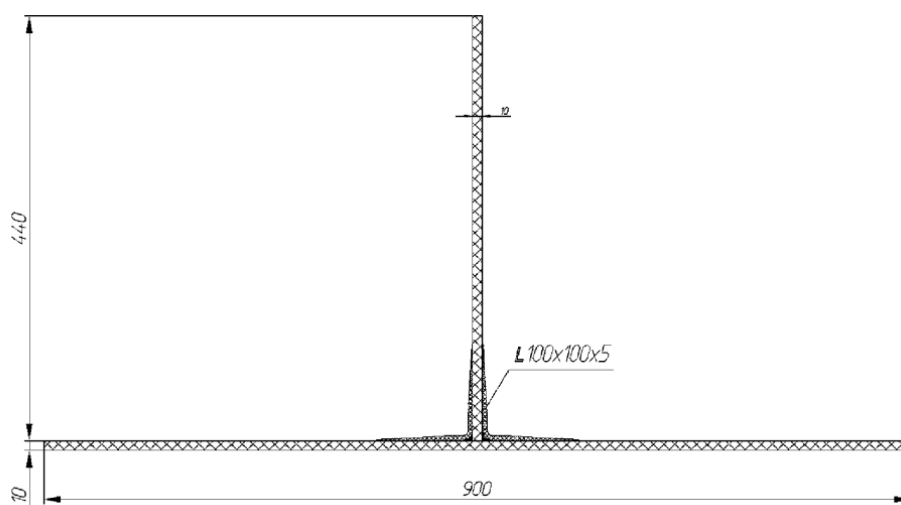


Fig. 6  
T-joint assembly for uniform separation test

## **5 INTRODUCTION OF AMENDMENTS INTO THE TEST PROGRAM**

**5.1** Proposals on amendments to be introduced into the test program are submitted by designers of FRP ships, firms (manufacturers) engaged in manufacture of structures and products using these materials, and by other interested organizations, with the technical background that such amendments are necessary.

**5.2** Proposed amendments shall be reviewed by the Register, and if approved, the test program shall be amended accordingly.

**TEST REPORT SAMPLE**

**1 GENERAL**

- 1.1** Item under test \_\_\_\_\_  
(item description (name) and characteristics)
- 1.2** Type of test \_\_\_\_\_  
(designation of the testing method with reference to the documents, in accordance with which the test has been conducted)
- 1.3** Ground for testing \_\_\_\_\_  
(contract No., name and address of the customer)
- 1.4** The test was attended by \_\_\_\_\_  
(full names and positions of the customer's representatives or official observers of the authorized body)
- 1.5** Date of delivery \_\_\_\_\_
- 1.6** Test period \_\_\_\_\_  
(test dates, including preparation procedures)
- 1.7** Test location \_\_\_\_\_  
(name and address of the testing laboratory)
- 1.8** Test conditions \_\_\_\_\_  
(environmental conditions)

**2 TESTING AND MEASURING EQUIPMENT**

- 2.1** Testing equipment \_\_\_\_\_  
(list of the testing equipment used, last certification date, certificate No. and validity periods)
- 2.2** Measuring equipment \_\_\_\_\_  
(list of measuring equipment used, their metrological performance, last calibration (verification) dates,  
\_\_\_\_\_  
certificate Nos. (calibration certificates) and validity periods)

**3 DOCUMENTATION**

List of normative and technical documentation used (performance specification, test program, test and measurement procedures, standards, technical specifications, etc.) shall be provided.

**4 TEST PROCEDURE (upon customer's request)**

Brief description of the test procedure, including test conditions (temperature, humidity, etc.) shall be provided.

**5 DEVIATIONS**

\_\_\_\_\_  
(list of deviations from the test and measurement procedures)

**6 SAMPLES**

\_\_\_\_\_  
(works performed shall be listed)

**7 TEST RESULTS**

Test results shall be provided in a form complying with the consumer's requirements, with indication of allowable tolerances.

**8 CONCLUSION**

Information confirming that test results are submitted in full according to the customer's requirements.

**9 APPENDIX**

Initial data of test results processing, and other relevant information shall be provided.

- Note :** 1. Upon the customer's request, the information to be provided in the Sections may be extended.  
2. Test results are valid only for the items tested.

Russian Maritime Register of Shipping

**Rules for the Classification and Construction of Sea-Going Ships**  
**Part XVI**  
**Structure and Strength of Fiber-Reinforced Plastic Ships**

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