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RULES

FOR THE CONSTRUCTION OF HULLS OF SEA-GOING SHIPS AND FLOATING FACILITIES USING REINFORCED CONCRETE

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RULES FOR THE CONSTRUCTION OF HULLS OF SEA-GOING SHIPS AND FLOATING FACILITIES USING REINFORCED CONCRETE

Rules for the Construction of Hulls of Sea-Going Ships and Floating Facilities Using Reinforced Concrete of Russian Maritime Register of Shipping (RS, the Register) have been approved in accordance with the established approval procedure and come into force on 1 July 2022.

The present edition of the Rules is based on the 2000 edition taking into consideration the amendments and additions developed immediately before publication.

REVISION HISTORY

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

For this version, there are no amendments to be included in the Revision History.

PART I. GENERAL REQUIREMENTS FOR CONSTRUCTION

1 GENERAL

1.1 Scope of application.

1.1.1 Rules for the Construction of Hulls of Sea-Going Ships and Floating Facilities Using Reinforced Concrete[1] apply to the sea-going ships, floating docks and other floating facilities[2], which hulls are constructed of reinforced concrete, steel concrete of integrated or composite design, that are under the Register technical supervision.

1.1.2 The reinforced concrete structures shall be used in construction of hulls of the ships and floating facilities based on the technical and economic feasibility of their use in specific conditions taking into consideration the maximum reduction in material consumption, power consumption, labor input and cost.

1.1.3 These Rules establish the general requirements for materials, design, strength and construction procedure for the ships and floating facilities specified in 1.1.1, which hulls are constructed using standard and prestressed reinforced concrete.

Where alternatives are used addressing the above issues, they shall be agreed with the Register. In this case the structures safety level shall be not lower than that provided by the requirements of these Rules.

1.1.4 When designing the hulls of ships and floating facilities using reinforced concrete, structural diagrams shall be taken providing the required strength, stability and spatial invariability of the structure as a whole, as well as separate structures at all stages of construction and operation.

1.1.5 For structures of the ships and floating facilities constructed of cast reinforced concrete, the standardized dimensions shall be provided that allow using the reusable formwork. Members of pre-cast structures shall meet the conditions of mechanized production taking into consideration their subsequent transportation and installation conditions.

1.1.6 In addition to the requirements of these Rules, the materials, design and construction procedure for hull structures and hulls of the ships and floating facilities specified in 1.1.1 shall meet the requirements of the normative documentation approved by the Register in so far as they meet the requirements of these Rules.

1.1.7 Equipment, arrangements and outfit, stability, subdivision, fire protection, machinery installations, systems and piping, boilers, heat exchangers and pressure vessels, electrical equipment, life-saving appliances and signal means, radio equipment and navigational equipment, cargo handling gear, etc. shall meet all applicable requirements of the relevant Register rules, state standards and other normative documents recognized by the Register.

1.1.8 The procedure and scope of surveys shall meet the requirements of the Guidelines on Technical Supervision of Ships in Service.

1.2 Definitions and explanations.

1.2.1 Concrete is hardened concrete mix (artificial stone).

1.2.2 Concrete mix is a mixture of cement, aggregates, various additives and water mixed in concrete mixers.

1.2.3 Concrete class is a guaranteed strength characteristic of concrete determined in accordance with the current standards.

1.2.4 Concrete grade is a guaranteed characteristic of concrete for watertightness, frost resistance, average density and self-stressing property.

[1] Hereinafter referred to as "these Rules".
[2] Hereinafter referred to as "the ships and floating facilities".

1.2.5 Steel for fittings is steel intended for the manufacture of fittings.

1.2.6 Fittings are steel bars of plain or periodic profile as well as steel plates or sections and 3D steel welded products used for reinforcement of concrete structures.

1.2.7 Reinforced concrete is a combination of concrete and steel bars, rolled or welded sections placed in concrete that work together in the structure as one solid unit.

1.2.8 Reinforced concrete structure is a structure made of reinforced concrete.

1.2.9 Steel-concrete structure is a concrete or reinforced concrete structure with bar fittings where, in the tension area (and sometimes in the compression area), the external plate fittings are used, which are installed on the extreme edges of the cross section and works together with the concrete or reinforced concrete structure.

1.2.10 Integrated (steel reinforced concrete) structure is a steel-concrete structure with rigid reinforcement made of rolled steel (steel welded structure) protected by concrete.

1.2.11 Composite structure is a single- or multi-element reinforced concrete, as well as steel-concrete or integrated structure and steel structure that are combined with each other and work together when exposed to external loads.

1.2.12 Reinforcement mesh is a tied-wire or welded mesh made of bar fittings and used to reinforce strip structures.

1.2.13 Reinforcement cage is a 3D or 2D structure that is made of bar fittings and used to reinforce structural members made of reinforced concrete.

1.2.14 Starter bars are ends of bar fittings protruding beyond the concrete surface; they serve to connect the hull members, to install and attach the equipment.

1.2.15 Embedded parts are plates, angles or metal parts of other form that are securely fastened in the concrete; they serve to connect the pre-cast structural members to each other, to install and attach the equipment and outfitting, as well as to connect metal structures to reinforced concrete ones.

1.2.16 Main reinforcement is fittings installed to provide the strength and crack resistance of structures according to the design.

1.2.17 Clamp, cross rod are fittings that take the shearing stresses in hull structures.

1.2.18 Protective concrete layer is the shortest distance from the external concrete surface to the fittings.

1.2.19 Formwork is wooden, wood-metal boards or boards made of other material that are used to construct the members and structures of the hull by cast-in-place method or when joint grouting.

2 MATERIALS

2.1 Concrete and its components.

2.1.1 Structural concrete shall be used for the reinforced concrete structures of the hulls of ships and floating facilities designed in compliance with the requirements of these Rules:

heavy-weight concrete air-hardened or heat-treated at atmospheric pressure with average density more than 2300 up to 2500 kg/m^3, inclusive;

light-weight concrete of average density more than 1800 kg/m^3 using dense fine aggregate;

fine-grained concrete air-hardened or heat-treated at atmospheric pressure using sand with fineness modulus more than 2,0;

special-purpose self-stressing concrete.

2.1.2 Concrete shall have the required strength, watertightness, frost resistance, chemical resistance to a given corrosive water environment, shall have low water absorption, and the concrete protective layer shall reliably protect the fittings against corrosion without installation of protective coatings.

The concrete resistance in corrosive water environment is provided by the use of materials, concrete mixes and aggregate factors in accordance with the requirements of the normative documentation approved by the Register.

2.1.3 To provide the required reliability and durability of the hulls of ships and floating facilities constructed with the use of reinforced concrete, concrete shall be used that has the appropriate strength classes and watertightness and frost resistance grades, especially in the areas of variable water level and exposure to ice. To improve the main properties of concrete (strength, impermeability, frost resistance and corrosion resistance), reduce water consumption, improve workability, reduce cement consumption, as well as to perform concrete works at negative ambient temperatures, special-purpose (air-entraining additives and plasticizers) are recommended for introduction into the concrete mix in accordance with the standards agreed with the Register.

As active mineral additive, fly ash may be used from thermal power plants that meets the requirements of the relevant normative documents.

Steel-concrete and integrated structures are recommended for use in the area of direct exposure to ice.

2.1.4 When designing the hull structures, the following main concrete quality parameters shall be established:

.1 compressive strength class B;

.2 axial tensile strength class B_t (shall be assigned when this characteristic is of the dominant importance and controlled in production);

.3 watertightness grade W (shall be assigned for structures that have requirements to limit water permeability);

.4 frost resistance grade F (shall be assigned for structures exposed to alternate freezing and thawing in wetted conditions);

.5 average density grade D (shall be assigned for structures that have requirements for thermal insulation in addition to the structural requirements);

.6 self-stressing grade S_p for self-stressing concrete (shall be assigned for self-stressing structures when this characteristic is taken into account in the design and controlled in production).

2.1.5 Depending on the type, purpose and operating conditions of hull structures, for their construction concrete with the following characteristics shall be used:

by strength:

compressive strength: classes B30, B40, B50, B60;

axial tensile strength: classes $B_t2,0$; $B_t2,4$; $B_t2,8$; $B_t3,2$.

Compressive and tensile strength class of concrete corresponds to the value of the relevant guaranteed strength of concrete, MPa, with 0,95 reliability;

by watertightness: grades W4, W6, W8, W10 and W12 are assigned depending on the pressure when testing the test specimens under the water pressure in accordance with the current normative documents recognized by the Register.

Notes: 1. For external structures exposed to sea water, its splash and in contact with ice features, the concrete watertightness grade shall be assigned not lower than W8.

2. For self-stressing concrete, the watertightness grade is provided not lower than W12 and may be not indicated in the designs;

by frost resistance: grades F50, F100, F150, F200, F300, F400, F500 are assigned depending on the operating conditions in accordance with the data given in Table 2.1.5;

Table 2.1.5

Climatic conditions	Average monthly temperature of the coldest month, °C	Corrosivity of water environment — salt content in 1 l of water, g	Number of freeze/thaw cycles during winter period	Design frost resistance grade of concrete
Moderate	From 0 to −10	0	Up to 50	F50
		0	From 50 to 100	F100
		From 0 to 10	Above 100	F150
Severe	From –10 to –20	0	Up to 50	F100
		0	50 to 100	F150
		From 0 to 20	Above 100	F200
Extremely severe	From –20 to –30	0	Up to 50	F150
		0	From 50 to 100	F200
		From 0 to 36	Above 100	F300
	From –30 to –35	From 20 to 36	Above 100	F400
	From –35 to –40	From 20 to 36	Above 100	F500

Notes: 1. Climatic conditions are characterized by the average monthly temperature of the coldest month in winter period: moderate: above –10 °C; severe: (–10 °C to –20 °C); extremely severe: below –20 °C.
2. For the region of construction and operation, the average monthly temperature of the coldest month is determined in accordance with the current normative documents and data of the hydrometeorological service.
3. When using concrete F300 or higher, introduction of plasticizers and air-entraining additives into concrete according to 2.1.3 is mandatory.
4. The requirements for frost resistance of concrete given in the Table shall be applied to the concrete of the external hull structures. Concrete of internal structures that are not exposed to water and weather impact shall have frost resistance grade not lower than F50.

by self-stressing concrete; $S_p0,6$; $S_p0,8$; $S_p1,0$; $S_p1,2$; $S_p1,5$; $S_p2,0$; $S_p3,0$; $S_p4,0$. The self-stressing grade of self-stressing concrete is the prestress value in concrete, MPa, created as a result of its expansion at longitudinal reinforcement factor μ = 0,01.

2.1.6 The concrete age is taken 28 days to determine its compressive and tensile strength class, watertightness grade and frost resistance grade. When the time of actual loading of structures by design loads, method of construction, concrete curing conditions, type and quality of cement used are known, the class and grade of concrete of a different age (60, 90 or 180 days) may be set. In all cases, exposure of concrete to external forces or other effects is allowed only upon achieving at least 70 % of the concrete strength of the class taken.

2.1.7 For heavy-weight shipbuilding concrete, cement consumption shall be taken 300 — 500 kg/m^3. In this case, depending on the climatic operating conditions of the structure, the water-cement ratio of concrete shall be taken not more than the values specified in Table 2.1.7.

Table 2.1.7

Climatic conditions	Water-cement ratio of concrete not more than	
	Concrete of above-water, underwater and variable-level areas	Concrete of internal structures
Extremely severe	0,38	0,42
Severe and moderate	0,40	0,42

2.1.8 For the hull structures exposed to severe operating conditions (number of freeze/thaw cycles in winter period is more than 100, the average monthly temperature of the coldest month is below –40 °C, salt content in 1 l of water is 20 — 36 g), the frost resistance grade of concrete shall be justified and specified based on the analysis of specific conditions of structure operation and results of dedicated studies and shall be agreed with the Register.

2.1.9 The controlled strength characteristics of concrete for hull structures: axial compressive strength and axial tensile strength shall be not lower than the values given in Table 2.1.9.

Depending on the concrete compressive strength, concrete strength characteristics are given in the first line of Table 2.1.9.

In cases where the tensile strength of concrete is not controlled in production, the concrete axial tensile strength characteristics are taken depending on the concrete compressive strength class in the second line of Table 2.1.9.

Table 2.1.9

Strength property	Designation and unit of measurement	Concrete strength grades					
		Heavy-weight concrete				Light-weight and fine-grained concrete	
		B30	B40	B50	B60	B30	B40
Concrete axial compressive strength (prism strength)	R_b, MPa	22	29	36	43	22	29
Concrete axial tensile strength	R_t, MPa	1,8	2,1	2,3	2,5	1,8	2,1
Initial modulus of elasticity	$E_b \cdot 10^{-3}$ MPa	31,5	35,0	38,0	40,0	26,0	28,5

Notes: 1. When using the intermediate compressive strength classes of concrete, the values of the characteristics given in the Table are taken by linear interpolation.
2. For self-stressing concrete, numerical values in axial tension shall be taken using a factor of 1,2.
3. Initial modulus of elasticity of concrete is the proportionality factor between the normal stress and the relative longitudinal immediate elastic deflection corresponding to it in axial compression of specimen at $\mu = 0{,}3R_b$.
For light-weight concrete, the initial modulus of elasticity shall be taken using a factor of 0,8.

In cases where the tensile strength of concrete is controlled in production, the concrete axial tensile strength characteristics are taken as equal to its guaranteed strength (class) in axial tension. As a design guide, it shall be taken into account that B — B_t relationship is determined by the dependence

$$B = (5{,}7 + 6{,}15\mathrm{B}_t)B_t.$$

2.1.10 To determine its strength class, watertightness, frost resistance and self-stressing grades, as well as the average density, the shipbuilding concrete shall be tested in accordance with the current standards.

2.1.11 Fine-grained concrete shall not be used without experimental justification for the structures exposed to repeated load.

2.1.12 For joint grouting of pre-cast structural members, concrete shall be used that has the strength class and the design frost resistance and watertightness grades not lower than those taken for the structures to be jointed.

2.1.13 The reinforced concrete hull structures shall be constructed of sulfate-resisting Portland cement concrete, plasticized sulfate-resisting Portland cement concrete or sulfate-resisting Portland cement concrete of grade not lower than B30. The mixture of different cements, as well as cement without supplier's data sheet are not allowed.

2.1.14 To prepare heavy-weight concrete, fractionated crushed stone with the grain size of 3(5) — 20 mm shall be used that complies with the current standards. As fine aggregate, natural quartz or feldspathic sand with the grain size of 0,15 — 3,5 mm, as well as artificial sand produced by crushing solid and dense rock shall be used that meet the standards agreed with the Register.

2.1.15 To prepare light-weight concrete, expanded clay gravel with the grain size of 5 — 20 mm shall be used that meets the standards agreed with the Register.

For the internal non-wetted hull members and superstructures, expanded clay gravel with the grain size of not more than 10 mm may be used.

2.1.16 Storage, transportation, use and quality control of cement as well as crushed stone and sand shall be carried out in accordance with the current standards.

During storage and transportation, cement shall be protected against moisture and contamination.

Cement shall be stored separately by types, grades and time of manufacture.

2.1.17 Water for concrete preparation shall meet the requirements of the standard for materials for shipbuilding concrete and provide high quality of concrete. The use of industrial, waste and swamp waters is not allowed.

2.2 Steel.

2.2.1 For reinforcement of the hull reinforced concrete structures, hot-rolled bar fittings shall be used that meet the requirements of the relevant standards or the technical specifications approved by the Register and belong to one of the following classes:

plain bars: class A-I;

deformed bars: classes A-II and A-III.

Steel for fittings that has undergone strengthening or profiling by cold treatment, as well as heat-treated reinforcement steel is not allowed for use. The use of fittings of new types developed by the industry shall be agreed with the Register.

2.2.2 By its mechanical properties, steel for fittings shall meet the standards given in Table 2.2.2.

Table 2.2.2

Mechanical properties	Class of steel for fittings		
	A-I	A-II	A-III
	killed or semi-killed		killed
Yield stress R_{eH}, MPa	≥ 235	≥ 295	≥ 390
Ultimate tensile strength R_m, MPa	≥ 373	≥ 490	≥ 590
Modulus of elasticity E, MPa	$2,1 \cdot 10^5$	$2,1 \cdot 10^5$	$2,0 \cdot 10^5$
Elongation A_5, %	≥ 25	≥ 19	≥ 14
Cold bend test (c — mandrel thickness, d — bar diameter)	180°c = d	180°c = d	90°c = 3d

2.2.3 Steel plates for hull steel-concrete, integrated and composite structures shall comply with the requirements of Part XIII "Materials" of the Rules for the Classification and Construction of Sea-Going Ships[1]. Rolled sections in the form of beams and channels may be used as rigid reinforcement that meet the requirements of the current standards.

2.2.4 For the hull structures used in severe and extremely severe climatic operating conditions (refer to 2.1.5 and 2.1.8), fittings of semi-killed steel with a diameter more than 16 mm is not allowed for use.

In structures exposed to alternating and vibration loads, steel for fittings of class A-III shall not be used if its carbon content is more than 0,3 %.

2.2.5 The embedded parts shall be made of shipbuilding killed or semi-killed steel, and their anchors shall be made of steel that meets the requirements of 2.2.1.

[1] Hereinafter referred to as "the Rules for the Classification".

3 STRUCTURAL REQUIREMENTS

3.1 General.

3.1.1 For the hull of ships and floating facilities made of reinforced concrete and of the hull members, the basic structure is, as a rule, a framing structure comprising strip structures that are stiffened by ribs or bulkheads, which form the transverse, longitudinal or combined system of cross members. Some hull members (bulkheads, platforms, stiffeners) may be made of steel.

3.1.2 Changing the structure and strength of the hull members shall be performed gradually over their length avoiding any stress concentration areas. For this purpose the following is recommended:

.1 the cross-section of bar fittings shall be changed mainly by jointing the bars of different diameters while maintaining an equal number of the bars and their consistent arrangement in the cross-section;

.2 for the strips, which contribute to the hull overall strength, fittings shall be broken at a distance of at least a quarter of the hull breadth, and for the strips, which do not contribute to the overall strength, at least 30 diameters of the larger of the broken bars. At the same time, the bar fittings shall be broken so that a change is not more than 25 % for strips and 50 % for girders at a single location in the cross-sectional area of the fittings located in the tension area;

.3 thickness of the shell plating and height of the framing girders shall be changed gradually with a slope of not more than 30°. In this case, difference in thickness of shell plating in the same cross section shall be not more than 25 %, and change in height of the framing girders shall be not more than 10 %;

.4 jointing angles of reinforced concrete members less than 120° shall be provided with chamfers of at least 25 × 25 mm or rounded at a radius not less than 25 mm.

3.1.3 Superstructures of ships and floating facilities with reinforced concrete hulls may be designed as strong and contributing to longitudinal bending of the hull, and as light and taking primarily local loads only.

The following conditions determine the contribution of a superstructure to the longitudinal bending of the hull:

.1 length of the superstructure shall be not less than six times its height;

.2 side walls of the superstructure shall be aligned with the hull sides and longitudinal bulkheads of the superstructure shall be aligned with the hull longitudinal bulkheads or supported at least by three of its rigid structural members (transverse bulkheads, deck transverses stiffened by pillars) and securely connected to them;

.3 end walls of the superstructures shall be aligned with the hull transverse bulkheads or there shall be structural members under the end walls of the superstructures that connect them to the hull sides or longitudinal bulkheads;

.4 design of the strong superstructure and hull connection shall provide their working together at the hull overall bending.

3.1.4 The superstructures longer than 0,15 of the hull length that meet the conditions of contribution to longitudinal bending shall be designed strong taking into consideration them as the upper face plate of the design cross-section. In this case:

.1 sides under the side walls of the strong superstructures shall have reinforcements of a length equal to a height of the superstructure forward and aft of the end bulkheads of the superstructures;

.2 size and reinforcement of the hull structural members under the strong superstructure at a length of 2,5 of the superstructure height (or one-third of the hull width) from the end walls shall be the same as outside the superstructure;

.3 size and reinforcement of the structural members of the strong superstructure in a section smaller than two times the superstructure height from its ends may be reduced to the values required to provide the local strength;

.4 decks and side walls of strong superstructures shall be continuous over their length.

3.1.5 The reinforced concrete superstructures that contribute to the overall longitudinal strength may be of a panel design consisting of ribbed or flat sections that are firmly tied together and constructed, in principle, in the same way as the members of the reinforced concrete hull.

Reinforced concrete superstructures that contribute to the overall strength may have a frame-and-panel construction consisting of a load-bearing frame made of separate stays and girders that are connected to the hull and to each other and of flat reinforced concrete panels that fill the areas between the frame girders.

3.1.6 The hull members shall be reinforced with bar fittings in the form of welded reinforcement meshes and cages.

The tied-wire reinforcement meshes and cages may be used in cast-in-place structures, which fittings are assembled at the place of manufacture and is not transported as assembled.

Note. The tied-wire meshes may be transported, provided the two outermost bars are welded around the mesh perimeter.

3.1.7 Connections of bar fittings to each other and to the elements of the parts shall be welded and made in accordance with the current standards. In this case:

.1 butt joints of bars shall be made by contact or arc welding (using side fillet welds or tub welding in grooved pads). In all cases, the welded joints shall be equal in strength to the joined bars and to a bar of smaller diameter when joining bars of different diameters;

.2 intersecting bars shall be connected by semi-automatic carbon-dioxide spot welding. In exceptional cases, manual welding may be done to connect intersecting bars in hard-to-reach places;

.3 bars shall be connected to metal structures by arc welding (seam welding, inert-gas spot welding or submerged welding).

3.1.8 Thickness of the shell plating and deck plates are recommended to be increased in the area of the bilge, deck stringer, ice belt as well as in the area where machinery, devices and equipment are installed.

3.1.9 The hull members that are exposed to intensive local abrasion, for example, the shell plating in the area exposed to ice, deck in areas of heavy movement of the machinery, etc., shall be coated with the metal or protected by wear-resistant or restorable coatings. The above hull members in contact with sea water, which are not coated, shall have the protective concrete layer thickness increased not less than by 5 mm.

3.1.10 The parts of the reinforced concrete hull, which may be exposed to impacts during operation shall be strengthened, metal-coated or protected by fenders, ceiling and other structures, which have sufficient strength, wear-resistance and reliability under such loads and which provide transmission of forces to the stiffeners and not to the plating.

3.1.11 The hull members, which are exposed to heat, shall have protection that protects the concrete against heating above 100 °C. In exceptional cases, concrete may be heated up to 200 °C, provided the design concrete strength is reduced by 25 %.

3.1.12 In the bottom framing members and non-watertight bulkheads of compartments and tanks, openings of sufficient area shall be provided for fluid overflow and free passage of air. Openings in the girders shall not cut through the main reinforcement and shall be located in the area of the maximum shear forces. The opening height shall not exceed half the height of the girder. A distance from the opening edge to the fittings shall be not less than the size of the protective concrete layer.

3.1.13 The protective concrete layer for the main reinforcement shall provide the combined action of the fittings with the concrete at all stages of the behavior of the structure, as well as the protection of the fittings against external corrosive as well as temperature effects of the environment.

3.1.14 To increase the corrosion resistance of the fittings in the underwater area and the area of variable water level, it is recommended that a cathode protection system be provided for the fittings including them in the unified corrosion protection system for all metal hull members.

3.1.15 Transverse fittings shall be installed in girder structures with a height of more than 150 mm, strips with a height (thickness) of more than 300 mm. No transverse fittings may be installed in lower or thinner structures.

3.1.16 In welded reinforcement structures, a ratio of diameters of cross rods and longitudinal bars is set such that the strength, structural requirements and welding are in accordance with the relevant regulatory documents agreed with the Register.

3.1.17 In the hull structures, bar fittings of the main reinforcement shall be brought beyond the cross-section normal to the longitudinal axis of the member (anchored), in which they are fully considered, by a length not less than that determined by the formulas:

$$l_{an} \geq \left(m_{an}\frac{R_s}{R_b} + \Delta\lambda_{an}\right)d; \tag{3.1.17-1}$$

$$l_{an} \geq \lambda_{an}d \tag{3.1.17-2}$$

where l_{an} = anchorage length;
R_s = design tension resistance of fittings;
R_b = concrete compressive strength;
d = bar diameter;
m_{an}, $\Delta\lambda_{an}$, λ_{an} = factors taken according to Table 3.1.17.

Table 3.1.17

Fittings operation conditions	m_{an}		$\Delta\lambda_{an}$	λ_{an}
	periodic profile	plain profile		
Embedding of tension reinforcement into tension concrete	0,7	1,2	11	20
Embedding of tension or compression reinforcement into compression concrete	0,5	0,8	8	12(15)[1]
Overlapped joints of fittings in concrete:				
tension	0,9	1,55	11	20
compression	0,65	1,00	8	15

[1] For plain reinforcement.

If it is not possible to achieve effective anchorage length l_{an}, action shall be taken to anchor the bar fittings to provide their operation at the full design resistance in the considered section: installation of lateral fittings, welding of anchoring plates or embedded parts to the ends of bars, bending of the bar ends into the compression area. A length of the straight section of the bend shall be not less than 10 diameters of the bar.

If the anchored bars are installed with a reserve of sectional area as compared to that required by the design, anchorage length l_{an} may be reduced by a value equal to a ratio of the area required by calculation to the actual sectional area of the fittings.

3.1.18 A thickness of reinforced concrete framing girders shall be not less than a thickness of the stiffened strips, and a height shall not exceed ten times their thickness.

3.1.19 Deck openings along the hull length shall, if possible, be arranged so that their axes are in line with one another, with the larger axis being along the ship. The corners of rectangular openings in deck strips or bulkheads are recommended to be rounded or blunted. Stiffeners shall be installed near the corners of large openings where there may be a hazardous concentration of stresses. In reinforced concrete structures, in this case, between the strip meshes, additional straight bars shall be installed that are normal to the angle bisector, and, when the angle is straightened or rounded, then parallel to its outline.

In all cases, the main reinforcement of the decks, which is cut through by an opening located at a distance equal to or less than 1,5 of the opening width from the side, or which width is greater than or equal to 0,15 of the hull width, shall be compensated by the installation of additional bars or structures. In this case:

.1 compensating bars shall be brought beyond the opening cross section by their 30 diameters if they are welded to the transverse fittings, and by 50 diameters if they are not welded to them;

.2 the cross-sectional area of the compensating reinforcement shall be not smaller than the area of the cut-through reinforcement of the same direction with the same strength characteristics of the compensating and main reinforcement. If the compensating and main reinforcement have different strength characteristics, the area of the compensating reinforcement may be changed in proportion to the yield stress ratio of the main and compensating reinforcement;

.3 the longitudinal fittings, which compensates the deck fittings cut through by the opening shall be located from the longitudinal edge of the opening at a distance no greater than half the distance of the longitudinal edges of the opening from the side. If this requirement cannot be met, the compensating reinforcement shall be placed in longitudinal reinforced concrete coamings securely joining it by welding to the deck main reinforcement;

.4 the design and reinforcement of reinforced concrete coamings shall correspond to the design and reinforcement of the primary hull members;

.5 corners of the openings that have metal coaming or skirting shall be rounded or blunted.

3.1.20 In the area where machinery and various devices are attached that transfer significant forces, the hull structures shall be stiffened by installing additional girders or by reinforcing the existing structural members. For this purpose, metal structures may be used that are securely connected to the hull members.

3.2 Reinforced concrete structures.

3.2.1 The dimensions of the hull reinforced concrete members and their reinforcement shall be determined by the calculations based on the conditions of their strength and crack resistance or limiting the crack opening in the structures where cracking in concrete is acceptable. In all cases, the cross-sectional area of the tension reinforcement shall be not less than 0,5 % of the area of the concrete cross-section of the member.

3.2.2 For bar fittings of the outer surfaces of the hull members, the protective concrete layer thickness shall be not less than 15 mm; for dock floor and intensively abraded areas of ship deck, not less than 20 mm; for internal wetted hull members, not less than 10 mm; and for internal hull members not exposed to corrosive factors, not less than 5 mm.

3.2.3 The reinforcement of reinforced concrete members shall be as dispersed as possible. In this case, a diameter of bar fittings of the main reinforcement shall be taken not less than 10 mm in girders, not less than 8 mm in strips, but in all cases, not more than 40 mm.

For cross rods and clamps, a diameter shall be not less than 6 mm.

3.2.4 A distance between the bar fittings in height and width of the structure cross section shall provide reliable combined action of the fittings with the concrete, ease of placement and concrete mix consolidation and shall be taken as follows:

in strips, a distance between the centerlines of the bar fittings of the same direction (bar spacing) shall be not less than 50 mm and not more than 200 mm. In this case, if a thickness of the strips is less than 80 mm, the bars of reinforcement meshes shall be placed in the strip section in staggered arrangement but not under each other;

in girders, a distance between the centerlines of bar fittings shall be not less than the largest diameter of the bars and not less than 20 mm, and also:

.1 when, during concreting, the bar fittings are arranged horizontally or in inclined position, not less than 25 mm for the bottom fittings, not less than 30 mm for the top fittings; when the bottom fittings are arranged in more than two rows in height, a distance between the bars in horizontal direction (except for bars of the two lower rows) shall be not less than 50 mm;

.2 in case of vertical position of bar fittings, not less than 50 mm and not less than one and a half times the largest size of coarse aggregate.

In constrained conditions, horizontal bars may be arranged in the structures in pairs (without a gap between them).

3.2.5 In girder structures, a distance between the cross rods that are vertical in relation to the member centerline shall be taken as follows:

.1 in the areas near supports (not less than 1/4 of the span) of the members up to 450 mm in height, not more than $h/2$ and not more than 150 mm; when a height of the member sections is more than 450 mm, not more than $h/3$ and not more than 500 mm;

.2 in the remaining part of the span with the section height more than 300 mm, not more than $3/4h$ and not more than 500 mm.

In the strips of the crushing area, the cross rods shall be installed with a spacing of not more than $h/3$ and not more than 200 mm, at that a width of the installation area of the cross rods shall be not less than $1{,}5h$.

3.2.6 If bar fittings of the main reinforcement are placed in two or more rows, the diameters of the bars in one row shall not differ from the diameters of the bars in the other row by more than 40 %.

3.2.7 Up to 25 % of the total number of tension reinforcement of a strip located above the supports may be made in the form of separate bars, which shall be brought to both sides of the support faces for a length of not less than 1/4 of the strip span.

In this case, a number of continuous bar fittings shall be not less than five per 1 running meter of the strip width.

3.2.8 Supporting sections of strips and girders may be strengthened by reinforced haunches with a slope of 1:3 and a height not more than half of the strip thickness (girder height). In this case, the bars specified in 3.2.7 shall not be used.

3.2.9 The minimum thickness of strips of the outer outline of the ships' and floating docks' hulls shall be taken not less than 80 mm and not less than 60 mm for other structures.

3.2.10 The framing girders shall be reinforced with welded cages installed at the side edges of the stiffener and connected at its top by welded cross rods or metal plates. The clear spacing between the latter shall be not more than 15 in the compression area, not more than 20 diameters of the longitudinal compression bars of the girder in the tension area, and in all cases, not more than 500 mm.

3.2.11 When reinforcing the girders with tied-wire cages, the cross rods covering the longitudinal bars shall meet the following requirements:

.1 the bar diameter shall be not less than 0,25 of a diameter of the longitudinal fittings, but not less than 6 mm;

.2 a distance between the clamps shall not exceed the least of the following values: 0,75 of the girder height; 15 diameters of the least enveloped longitudinal bars of the compression reinforcement or 250 mm; in centric- or eccentric-compression members, the above distance shall not exceed 1,5 of the member thickness.

3.2.12 The main reinforcement of the girders in the form of separate bars shall meet the following requirements:

.1 main reinforcement shall be arranged both in the compression and in the tension areas in not more than three rows in height and not less than in two rows in width;

.2 clear spacing between adjacent bar fittings that are arranged parallel to each other or intersect at an angle of not more than 15° shall be not less than a diameter of the largest of them and not less than 20 mm, and for the girders less than 10 cm in width, not less than 10 mm;

.3 each clamp shall cover not more than six compression bars; if an area of the compression fittings exceeds 3 % of the cross-sectional area of the member, spacing between the clamps shall not exceed 10 diameters of the longitudinal bars;

.4 the inclined fittings shall be made by bending the longitudinal fittings with a bending radius not less than 10 diameters or by installing separate inclined bars that end in straight sections lap-welded to the longitudinal fittings; an angle of inclination of these fittings shall be not less than 30 and not more than 60°;

.5 when the girder height is more than 700 mm, structural longitudinal bars shall be installed along its side edges with spacing along the member height not more than 400 mm and the cross-sectional area not less than 0,1 % of the concrete cross-sectional area, a height equal to a spacing between the bars and a width equal to half the member width but not more than 200 mm.

3.2.13 If the strips crossing each other form a T-beam, the main reinforcement of the strip, which is the T-beam wall, shall be anchored in the other strip. Anchoring shall be done by bending an anchored bar in the plane of the strip, which is the T-beam leg, around the bars with a diameter of not less than 8 mm installed between its meshes, parallel to the plane of the strip that forms the T-beam wall, and in case this requirement cannot be met, around the fittings of external reinforcement mesh of the strip. In this case, a length of the straight section of the bend shall be not less than 10 times the bar diameter.

3.2.14 In case of fillet joint of the strips, the main reinforcement shall be connected by welding or through strips, and when welding is not possible, it shall be passed from one strip to another at a distance of not less than its 30 diameters.

3.2.15 The following requirements shall be met when crossing the members:

.1 all tension bar fittings shall be retained and passed from one structure to another;

.2 at the intersections of the members, the compression bar fittings may be broken with the break place being brought beyond the support face by a value not less than required by 3.1.17.

3.2.16 When the heights of the intersecting girders differ by more than 20 %, the low girder is recommended to be connected to the high girder using a reinforced haunch with a slope of 1:3 and not more than half the height of the girder. The haunch edge shall be reinforced by haunch bars covered from the outside with haunch clamps spaced at the same distance as the haunch width.

3.2.17 When connecting the girder to the strip, each clamp (cross rod of the girder framework) shall be anchored by bending the anchored bar in the strip plane around 24 bars of not less than 8 mm in diameter installed between its meshes parallel to the longitudinal axis of the girder, or, when this requirement cannot be met, around the bars of the external reinforcing mesh of the strip. In this case, a length of the straight section of the bend in the strip shall be not less than 10 diameters.

Closed clamps shall be anchored by longitudinal bars located between the meshes of the strip.

3.2.18 Local strengthening of reinforced concrete hull structures shall be done by thickening the strip with additional meshes being placed in it, as well as by installing dedicated girders. Strengthening edge of strips shall be made at an angle of not more than 30°. Strengthening girders shall be brought to the girders or bulkheads of the other direction and firmly connected to them in compliance with the requirements of 3.1.7 and 3.1.17.

3.2.19 Foundations of machinery, equipment, ship arrangements and outfit elements shall be attached to the reinforced concrete hull structures by means of welding to the embedded parts or by means of anchor bolts, which dimensions shall be justified by calculation. Attachment may be made using passing bolts, as well as dowels of equipment, devices and outfit to the framing girders, as well as to the hull strips, for which there are no watertightness requirements.

Attachment by means of anchor bolts with a diameter more than 12 mm to the shell plating and watertight bulkheads is not allowed.

3.2.20 The embedded parts installed in the section plane shall be secured in the concrete not less than by two anchoring bars. Not less than four anchoring bars in two rows shall be provided for the parts that take shear forces. The anchoring bars shall be made of periodic-profile fittings. Plain anchoring bars may only be used if they have strengthening at their ends in the form of plates, butten heads and short cross rods.

3.2.21 Anchoring bars in the form of bent bars (cleats), as well as shortened bars with bent ends (pawls) may only be used in cases where they are installed for design reasons and fix the structures that are not exposed to tearing, vibratory or dynamic loads.

3.2.22 The cross-sectional area of the anchors shall, in general, be taken as the sum of the cross-sectional areas $F_{an.t}$ and $F_{an.w}$ of the anchor bars that take tension and shear forces, respectively.

The cross-sectional area of the anchors that take the tension forces is determined by the formula

$$F_{an.t} = FR_{eH}/R'_{eH} \qquad (3.2.22\text{-}1)$$

where F = cross-sectional area of tension reinforcement of structural member welded to embedded part;
R_{eH} = yield stress of metal of tension reinforcement welded to embedded part;
R'_{eH} = yield stress of anchoring bars steel.

The cross-sectional area of the anchors that take the shear force is determined by the approximate formula

$$F_{an,w} = Q/0{,}7R'_{eH} \qquad (3.2.22\text{-}2)$$

where Q = shear force.

3.2.23 A length of the anchoring bars shall be not less than their 15 diameters.

When this requirement cannot be met, the anchor length may be reduced to three diameters, provided any of the following elements are welded normal to the ends of the anchors (refer to Fig. 3.2.23):

a square plate not less than 5 mm thick with the square side of not less than four anchor diameters or 30 mm, whichever is greater;

round washers of not less than 5 mm thick and a diameter of not less than three diameters of the anchor or 30 mm, whichever is greater;

two cross rods of the same diameter as the anchor with a length equal to five diameters of the bar (at $d \geq 12$ mm) or the same bar at $d < 12$ mm.

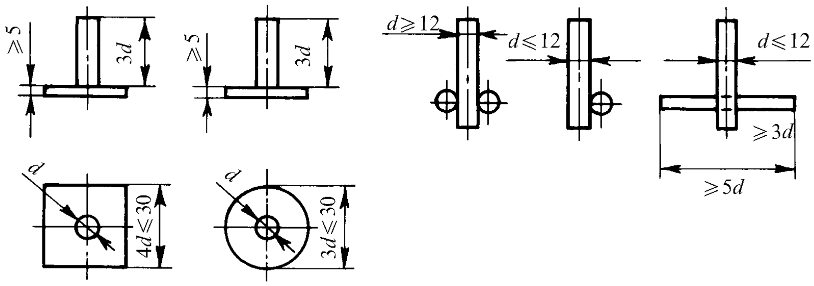

Fig. 3.2.23

3.2.24 A thickness of the plates of the embedded parts, in mm, installed in the section plane depends on a diameter of the anchoring bars and shall meet the following condition:

$$s = 0{,}5dR'_{eH}/R_{eH} \geq 5 \quad (3.2.24)$$

where R'_{eH} = yield stress of steel of anchoring bars;
R_{eH} = yield stress of plate steel;
d = diameter of anchoring bars, mm.

3.2.25 Attachment to the embedded parts shall be made taking into consideration the following:

.1 welding may be done directly to the embedded straps installed in the hull plates exposed to permanent action by liquid (e.g., bottom, sides, bulkheads and tank decks, etc.) when the embedded bars will be concreted after welding. In this case, welding shall be done by spot or intermittent welds;

.2 continuous welding may only be done to the embedded parts installed in the girders, water, oil and gastight hull members, as well as to the portions of the embedded parts that are spaced not less than 50 mm from the surface of the strips.

3.2.26 Joints on starter bars shall be used to connect sections of the shell plating and watertight bulkheads. All fittings cut at the joint shall be welded in accordance with the requirements of 3.1.7.

In all cases where the fittings are welded with continuous welds, a distance from the weld to the concrete surface shall be not less than 50 mm.

3.2.27 Section joints shall be located in convenient places for installation, welding and concreting of the intersectional joint. The horizontal joints shall be avoided in the vertical elements. It is allowed combining in one T-joint the connection of the skin plates and the bulkhead plate adjacent to them.

3.2.28 T-joints and fillet joints located inside the hull or superstructure may be made using embedded parts or by combined method in compliance with the following requirements:

.1 dimensions of the embedded parts, their arrangement, anchoring, and connection joints shall be established by calculation based on the condition of providing the required strength and stiffness taking into consideration the requirements of 3.2.20 — 3.2.25;

.2 maximum distance between the embedded parts shall be not more than 500 mm, and not more than 200 mm in joints covered by the watertightness requirements;

.3 each embedded part shall be welded not less than to two starter bars. The dimensions of the embedded parts and their anchors shall not interfere with the quality placement of concrete during fabrication of section and joint grouting.

3.3 Steel-and-concrete and integrated structures.

3.3.1 When designing steel-concrete and integrated structures, normal heavy-weight concrete shall be used that has the strength classes specified in 2.1.4.

With appropriate experimental justification, expanded aggregate concrete of class not lower than B40 may be used.

3.3.2 As the main reinforcement in steel-concrete and integrated structures, steel plates and strips, welded elements made of steel plates and strips, and sections shall be used that meet the requirements specified in 2.2.3.

As bar fittings in steel-concrete and integrated structures, round bars shall be used that meet the requirements of 2.2.1 and 2.2.2.

3.3.3 When designing steel-concrete and integrated structures, their reinforced concrete parts shall be designed in accordance with the requirements of 3.1 and 3.2.

3.3.4 In steel-concrete and integrated structures, special attention shall be paid to anchor ties along the contact length of the plate fittings and the reinforced concrete structure in order to provide their reliable combined action when exposed to external forces of all types. The reliable anchoring connection of the plate and section fittings to the reinforced concrete structure is one of the main conditions for the serviceability of steel-concrete and integrated structures.

3.3.5 When selecting the design of the anchors to be used in steel-concrete and integrated structures (flexible anchors of bar fittings lap- or T-welded to the plate reinforcement or anchors made of angles, plates not reinforced or reinforced with stiffeners, or a combination of these types of anchors), their simple and reliable attachment to the sheet fittings by means of welding shall be assumed.

3.3.6 In steel-concrete and integrated structures that work in bending, rigid end connectors shall be provided in the end area to obtain the required anchoring of the external plate fittings at the ends and the secure fixing of the element ends beyond the faces of the supports. The strength of such connectors shall be adequate to the ultimate design force in the external sheet steel reinforcement. A height of such structural members that fall within the steel plate fittings of unit width may be determined by the formula

$$h \geq R_{si} f/(1{,}2 R_b b) \qquad (3.3.6)$$

where R_{si} = design resistance of steel plate fittings;
f = design cross-sectional area of steel plate fittings of unit width;
R_b = design strength of concrete;
b = width of cross-section of element under consideration.

3.3.7 The external steel plate fittings of the steel-concrete and integrated structure shall be reliably secured against loss of stability (buckling between the anchors) under compressive stresses from the loads acting on the structure. To provide the stability of the external plate fittings under the compressive stresses, the anchor spacing shall be taken to be not more than the value determined by the formula

$$a \leq 15t\sqrt{2100/R_{si}} \qquad (3.3.7)$$

where t = sheet thickness of steel sheet fittings.
R_{si} = design resistance of steel sheet fittings.

3.3.8 Bar fittings shall be installed in steel-concrete and integrated structures where they are required in accordance with the requirements for the location of bar fittings in reinforced concrete structures of the relevant purpose.

In integrated structures, a diameter of longitudinal bar fittings shall be not less than 12 mm.

3.3.9 In integrated structures, the cross-section of rigid reinforcement shall be selected as minimum one based on the possibility to only use it as steel structure for the forces arising in the process of manufacture of the hull structures. It is recommended that the full operating load be provided by appropriate selection of rigid reinforcement and bar fittings in the cross-section of the integrated structure.

3.3.10 In all cases, a thickness of the protective concrete layer shall be not less than 50 mm for rigid reinforcement.

For structures operating in corrosive environment, a thickness of the protective concrete layer shall be specified taking into consideration the requirements for the protection of structures against corrosion, as well as fire safety standards for design of structures.

3.3.11 When reinforcing the integrated structures with twin rigid reinforcement in the form of I-beams, channels, etc., the clear distance between their elements shall be:

not less than 80 mm when reinforced using channels with their walls facing each other;

not less than 50 mm when reinforced using channels with the flanges facing each other and using I-beams.

3.3.12 The joints of rigid reinforcement shall provide the transfer of the design forces at the points where the elements are connected. The connection of the rigid reinforcement elements shall be designed in accordance with the requirements for the connections of metal structures taking into consideration the requirements of their concreting procedure.

3.4 Composite structures.

3.4.1 When designing the composite structures, the following requirements shall be met:

.1 dimensions of reinforced concrete and steel elements of the composite structures shall be specified based on the condition to provide the sufficient strength and reliability of both the elements themselves and the joints. At the same time, corrosion allowances shall be taken into account for steel members;

.2 steel bulkheads, frames, framing girders and other members shall be in the same plane as the relevant reinforced concrete members.

Intermediate girders or other stiffeners may be installed in steel structures that are not in the same plane as the reinforced concrete members, provided these elements are securely anchored in reinforced concrete strengthening that is capable of taking the forces that occur at this assembly.

3.4.2 Steel elements of the composite structures shall be attached to the reinforced concrete ones with dedicated embedded parts or anchors, which number and strength shall be sufficient to transfer to reinforced concrete all forces acting in the connection. In this context, the following requirements shall be met:

.1 at the point of their connection to the embedded parts or anchors, the ends of the metal girders shall be reinforced with brackets;

.2 when T-connecting a steel element exposed to tear to an embedded part, the anchors of the latter shall be located in the plane of said element. If the connection works mainly in bending or shear, the anchors that secure the part shall be arranged along the width of the strap in two or more rows. When such a connection is loaded by tearing forces, the strap of the embedded part shall be sufficiently strong to take the transverse bending between the anchors;

.3 the ends of bar fittings of the main reinforcement of reinforced concrete members may be used as anchors to secure the steel members, provided they do not have to be bent away from the main direction at an angle exceeding 30°. If, while doing so, this results in significant additional stresses in the main reinforcement, it shall be strengthened by increasing a diameter or installing additional bars.

3.4.3 Steel towers of composite docks, steel members and structures of composite ships shall be welded with a continuous double-sided butt weld or T-weld to the solid embedded parts installed in the reinforced concrete hull (refer to Fig. 3.4.3). The joints subject to watertightness requirements are recommended to be made according to Figs. 3.4.3, *a*, *c* and *d*, and the others according to Fig. 3.4.3, *b*. In this case, it is required that:

.1 steel structure shall be connected to the reinforced concrete one, an embedded part being not less than 5 mm thicker than the connected steel plates;

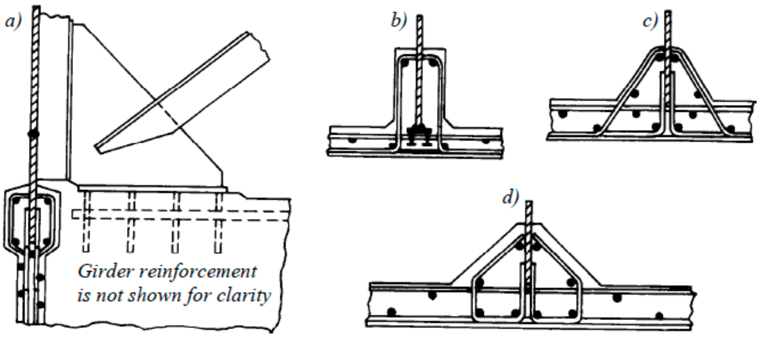

Fig. 3.4.3

.2 joint weld shall be not less than 50 mm away from the concrete;

.3 joint of the embedded part to the reinforced concrete structure shall be edged with reinforced concrete strengthening on both sides not less than 150 mm in height and not less than 100 mm in width;

.4 the reinforcement cage shall be formed of longitudinal bars not less than 10 mm in diameter and closed clamps of not less than 8 mm in diameter spaced at intervals of not more than 100 mm. A distance between the embedded sheet and the longitudinal bars of the cage shall be not less than 20 mm;

.5 where the embedded sheet intersects the clamps, the latter shall be edge-welded to the sheet, and when there are bends, using side fillet or spot welds. When the clamp is passed through the sheet, it shall be welded around the perimeter of the opening in watertight joints;

.6 where the embedded sheet intersects the reinforced concrete girder, the continuity shall be provided for the longitudinal and bent bar fittings that are required in it by design and shall be passed through this sheet or edge-welded to it;

.7 where required, additional fittings or connectors shall be installed and welded to the embedded sheet to take shear forces that act in the plane where the concrete is adjacent to that sheet;

.8 in all cases, the sheet embedded in concrete shall not intersect the watertight strips.

3.4.4 Welding of steel elements of composite structures shall be done in accordance with the requirements for joints of similar elements contained in the relevant Parts II "Hull" and XIV "Welding" of the Rules for the Classification.

3.4.5 All exposed metal surfaces of the composite structures as well as protruding metal parts of connections shall have corrosion-resistant coatings made according to the procedure recognized by the Register.

3.4.6 Top-deck structures of steel towers of composite docks shall be constructed as cambered or with a double slope.

4 TECHNOLOGICAL INSTRUCTIONS

4.1 The main methods of the hull and superstructure construction are pre-cast method where the hull and superstructure are assembled of pre-cast flat sections, and modular method where the hull is assembled of 3D modules, each of which is assembled of flat sections.

4.2 The pre-cast and cast-in-place method may be used to construct the hulls or their separate 3D modules where mostly vertical members (sides, bulkheads, transoms) are assembled of sections, and the cast-in-place method to construct horizontal members (bottom, deck), as well as separate strengthening and stiffeners, areas of irregular shape or with a large amount of fittings and embedded parts.

When using the pre-cast and cast-in-place method, preference shall be given to such a sequence of works where the cast-in-place elements are concreted after the adjacent sections are installed.

4.3 The cast-in-place method may be used for the hull construction for ships with specific features (irregular hull shape, large strip thicknesses, special requirements for watertightness, construction a float, etc.). The technology of cast-in-place and concrete works to manufacture cast-in-place elements shall be in accordance with the normative documentation approved by the Register.

4.4 The slipway for the construction of the reinforced concrete ship shall have sufficient strength and a rigid base, which prevents the possibility of non-uniform subsidence of the supports in excess of the tolerances. The deformation of the slipway shall be controlled at various points by rack and pinion tell-tale or by other means. The structure of the slipway shall provide the possibility of external examination of the whole area of the ship's bottom.

4.5 The requirements for the manufacture and installation of hull structures, butt and intersectional joints of the hulls constructed with reinforced concrete shall meet the requirements of these Rules, as well as the Guidelines for Technical Supervision during Construction of Ships and Manufacture of Materials and Products for Ships. The manufacturing technique of metal elements of hull structures, as well as metal parts of composite hull structures shall be similar to the manufacturing technology of steel ship structures.

4.6 Sufficient strength and stiffness of the sections during transportation, storage and, in some cases, also during demolding shall be confirmed by the calculation made in accordance with the requirements of 2.3, Part II "Making Calculations and Strength Standards" as related to specific conditions of strapping, support, etc. For the large-size non-ribbed sections with openings that weaken the structure, the Register may require the experimental verification of the section strength during transportation.

4.7 To accelerate the concrete curing, concrete may be heated (steamed) both during the manufacture of separate structures and structures forming the part of the hull by filling the relevant compartments with steam. Steaming shall be done with saturated steam and provide that at least 70 % of the design strength of the concrete is obtained immediately after steaming.

4.8 The surfaces of joints during breaks in concreting and the edges of butted concrete members to remove the cement skin shall be treated over the entire area of contact with the newly placed or grouting concrete for all watertight structural members that operate under action of the maximum design forces for the given structural member type. In this case, the strength of intersectional attachments (joints) of the hull members shall be checked:

.1 for joints with welded starter bars that are extensions of the main reinforcement, as for similar cast-in-place members;

.2 for joints on embedded parts, based on the loading diagram of the joint elements with the strength check of fastening of embedded parts and individual anchors, taking into consideration Appendix 4.

Watertight elements may be jointed without the edge treatment with the mandatory check of the joint for strength by the method agreed with the Register. As the allowable value of shear stresses in concrete in this case, it may be taken $\tau = 0{,}8R_t$.

4.9 Concrete with the characteristics specified in the design shall be used for concreting separate hull parts and intersectional joints. In this case, the following shall be taken into account:

.1 maximum grain size of aggregate in the concrete mix shall not exceed 10 mm;

.2 concrete-mix consistency shall be with cone slump not more than 8 cm for horizontal joints and not more than 15 cm for vertical joints;

.3 for mechanized concreting of intersectional joints, sand concrete may be used with a density of 2280 kg/m^3 and water-cement ratio not more than 0,42.

In all cases, the concrete of intersectional joints shall have the strength, watertightness and frost resistance not lower than that required for the concrete of the hull members to be jointed.

4.10 Concreting defects and mechanical damage shall be eliminated by complete removal of all weak concrete (with fittings being corrected where necessary) followed by filling the defective area with concrete of the same quality as used for concreting of intersectional joints. For defects in the form of cracks or small holes (air holes) the sufficient-width edge preparation shall be preliminary made for high-quality filling the former with concrete to their full depth.

N o t e . To repair minor defects or damages, epoxy-based polymer concrete as well as cement colloidal adhesives may be used in accordance with the instructions approved by the Register.

4.11 The hull parts may be jointed a float from separately built floating modules if the accepted design and procedure of the modules connection into one whole provide the strength and watertightness of the cast-in-place hull in accordance with the design.

PART II. MAKING CALCULATIONS AND STRENGTH STANDARDS

1 GENERAL

1.1 Main instructions for calculation.

1.1.1 For the hull structures manufactured using normal reinforced concrete in accordance with the requirements of Part I "General Requirements for Construction", the strength calculations shall be made according to the requirements of this Part. The instructions for the strength check of the prestressed reinforced concrete hull structures are given in Part III "Specific Construction of Prestressed Reinforced Concrete Hulls".

1.1.2 The strength of the hull and its separate members in longitudinal bending shall be checked in the following most critical sections along its length:

.1 in the area of the maximum moments and shear forces;

.2 in the areas of changes in the hull design or changes in the dimensions and reinforcement of the structural members included in the design cross-section;

.3 in the areas loaded by the highest local loads.

1.1.3 The strength calculations of the hull in its longitudinal bending shall be made as for a composite-section girder consisting of longitudinal hull structural members that contribute to longitudinal bending, namely, the longitudinal hull structural members located in the section under consideration and running continuously to each side of the section under consideration over three moulded depths if their connection to the hull provides their full contribution to longitudinal bending. In this case:

.1 at their connection to the deck and bottom plating, the vertical hull members shall be included in the calculation of the cross-section with their adjacent plating areas, which width is taken to be half the frame space or ten thicknesses of the plating, whichever is greater;

.2 single openings with the largest dimension (diameter) less than five thicknesses of the strip may be omitted in the calculations. Non-stiffened openings, which width does not exceed 15 % of the deck width, may also be omitted in determination of the design cross-section elements. However, the forces in the deck thus obtained shall be increased in proportion to a ratio of the reduced cross-sectional areas of the deck without and including the openings. The openings reinforced in accordance with the requirements of 3.1.18, Part I "General Requirements for Construction" shall be also omitted in determination of the design cross-section elements;

.3 steel structures of composite ships and floating docks shall be included in the design cross-section in accordance with the requirements of Part II "Hull" of the Rules for the Classification.

1.1.4 The hull structures shall meet the calculation requirements: in terms of load-carrying capacity, failure under the combined action of force factors and adverse effects of the external environment, fatigue failure, loss of stability of the structure shape (for thin-walled structures) or its position (ultimate limit states); in terms of serviceability, crack initiation in reinforced concrete structures or excessive crack opening if crack initiation in concrete structures is acceptable (serviceability limit states).

1.1.5 The strength calculations of hull structures shall include:

determination of values and characteristics of external design loads;

determination of the maximum internal forces in critical sections of a structure under design loads;

determination of load-carrying capacity limit values (strength with stability considered where necessary) of forces in critical sections for the structure being calculated;

verification of the strength criterion by comparing the internal force from the external design load with the allowable load value for the structure or assembly cross-section under consideration by dividing the critical (breaking) value of the force for this section or assembly by the corresponding safety factor and, on this basis, making assessment of the strength of the structure being calculated;

determination of crack resistance force or the value of design crack opening in the most stretched concrete fibres;

comparison of the crack resistance forces of the structure with the forces acting on it or the value of the design crack opening in the most stretched concrete fibres with the value of the allowable crack opening stipulated by these Rules.

1.1.6 The design loads acting on the hull and its separate parts shall be determined in accordance with the requirements of Part II "Hull" of the Rules for the Classification. The design load is taken as the combination of external loads, at which the highest stressed condition of the structure occurs.

1.1.7 When calculating the strength of the hull structures, the internal forces (normal and shear forces, bending moments), as well as displacements and rotation angles shall, in general, be determined taking into consideration the inelastic behavior of the structures due to crack initiation and concrete creeping, non-linear relationship between stresses and deformations of materials by the methods agreed with the Register. In case the methodology for calculating the structure with regard to its inelastic behavior has not been developed, the forces (stresses) in the cross-sections of the members may be determined, assuming the elastic action of the structure, by the methods of structural mechanics and strength of materials taking into consideration the requirements of these Rules.

1.1.8 Strength calculation of hull structures shall be made for sections normal to the longitudinal axis, as well as for the sections inclined to the axis of the most critical direction. When there are significant concentrated loads acting in limited areas normal to the axis of the member, the strength of the member shall, where necessary, be checked against this local load (buckling, crushing).

1.1.9 The strength conditions of hull members in normal sections are as follows:

.1 under action of bending moment

$$M \leq M_u/k; \tag{1.1.9.1}$$

.2 under action of longitudinal force

$$N \leq N_u/k; \tag{1.1.9.2}$$

.3 under simultaneous action of bending moment and longitudinal force by Formula (1.1.9.2) and determining N_u as for eccentrically loaded structure at eccentricity

$$e_0 = M/N. \tag{1.1.9.3}$$

Here eccentricity e_0 is considered large if the longitudinal force is applied beyond the centre of gravity of the most stressed fittings in the cross-section and small if the longitudinal force is applied between the centres of gravity of the fittings located in the member cross-section.

For bent and eccentrically loaded members (except for eccentric-tension members with small eccentricity), eccentricity e_0 is calculated from the axis of the member passing through the geometric centre of gravity of its section and is plotted to the side of section where the stresses from M and N are summed up. For eccentric-tension members with small eccentricity e_0 is plotted from the centre of gravity of the area of the entire fittings of the section;

.4 strength condition for the hull members at inclined sections is written in the following form:

$$Q = Q_u/k_1 \quad (1.1.9.4)$$

where M, N and Q = bending moment, axial and transverse forces, respectively, due to design load (refer to Appendix 1);

M_u, N_u and Q_u = design breaking moment, design breaking axial force in normal section and design breaking force in inclined section of member determined in accordance with the instructions of Appendices 2 and 3;

k_1 and k = safety factors taken according to Table 1.1.9.4.

Table 1.1.9.4

Failure pattern of structure	Considered load[1]		
	constant forces	constant and random forces, and also random forces only	emergency forces
Concrete reaching compressive strength or fittings reaching yield stress k	1,6/1,4	1,4/1,3	1,2/1,2
Shear of concrete compression area under action of transverse force k_1	2,3/2,1	2,0/1,9	1,8/1,7
[1] Numerator is the considered load for the members that contribute to the overall and local strength simultaneously, as well as compressed, denominator is the same for the members that contribute to the local strength only.			

In this case, if the calculation of the simultaneous action of constant and random forces or the calculation of emergency loads provide the safety factors given in Table 1.1.9.4, the appropriate safety factors shall, under action of constant forces alone, be provided not less than those specified in the Table.

Notes: 1. Constant load is a load that acts at all times or for a significant period of time: water pressure on underwater hull at still water load line draught, cargo weight; deadweight of structure; still water hull load, fuel, water or oil pressure on tank bulkheads, etc.; weight of estimated docked ship (for floating docks); forces transferred to hull due to operation of equipment and arrangements installed on the ship, as well as due to ship mooring at anchorage, etc.

2. Random (temporary) load is a load that acts a limited number of times: during testing; locally on the ship's hull at docking; load on the hull as a whole and on its separate structures during the ship navigation in the most severe conditions taken as design ones; on the walls of tanks (fuel, ballast and fresh water) at the maximum head and irregular ballasting; due to waves at the ship passage; ice load; at impact of mooring ships; at docking of off-design ship (for floating docks); during construction (launching, jointing afloat, hull or module moving on slipway, transportation and stockpiling of sections, de-molding of sections, etc).

3. Emergency load is a load that may lead a part of hull structures to the condition requiring their replacement or repair but not causing destruction of the hull as a whole: longitudinal bending moments during flooding of a compartment, during grounding or collision with shore (wall); loads on bulkheads with compartment flooded, on dock structural members, due to incorrect installation of docked vessel or relocation of keel blocks, etc.

1.1.10 During design, in addition to the calculation of hull structures for the most adverse external design loads, the strength and crack resistance of all pre-cast reinforced concrete members shall be checked as well as their overall and local strength during transportation of the hull on the slipway and launching on the water.

In this context:

a weight of the member multiplied by dynamic coefficient k_D = 1,5 (with proper justification, the dynamic coefficient may be reduced to k_D = 1,3) is taken as a load during transportation and installation of the pre-cast members;

safety factors shall be taken:

not less than 1,8 during transportation and installation of pre-cast members when checking the structural strength for action of shear force and not less than 1,5 in other cases;

during transportation of the hull on the slipway and launching, not less than 1,6 for structures that provide the overall strength and not less than 1,5 for structures that provide the local strength of the hull;

grips and pads for lifting, transporting and stacking of the members shall be arranged in such a way that in this case the strength is provided without additional reinforcement.

1.1.11 Strength calculation of the steel-concrete and integrated structures, as well as composite hull structures shall be made after deduction of corrosion allowances for steel members.

In case of one-time extreme loads of the hull during its operation (during sea passage in waves, at repairs, etc.), the strength check shall be made with the actual thicknesses of its steel structures at the time of the given loading.

1.1.12 The framing girders of reinforced concrete, steel-concrete and integrated structures firmly connected by clamps or otherwise to the adjacent strips, which thickness is not less than 0,1 of the girder height are considered in the strength calculations as having a T-section with the width of the effective flange equal to the minimum of the following values: half sum of the adjacent strip span, 1/3 of the design span of the girder or 20 thicknesses of the strip (25 thicknesses of the strip in the case of haunches).

1.1.13 In the strength calculations of girders and strips that have reinforced haunches at the support intersection, the design height of the support sections of these structures may be increased in comparison with a height in the span by a value equal to the haunch height but by not more than 1/3 of its length.

1.1.14 At inclined sections, the hull structures shall be checked in the sections that pass through (refer to Fig. 1.1.14):

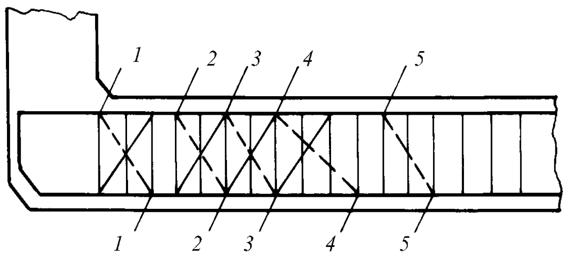

Fig. 1.1.14

.1 face of support (at *1-1*);
.2 beginnings of bends located in the tension area (at *2-2*, *3-3*, *4-4*);
.3 change points of clamp spacing located in the tension area (at *5-5*).

1.1.15 When checking the strength of inclined cross-sections of hull members that have bends of the main reinforcement, the design shear force is taken as follows (refer to Fig. 1.1.15):

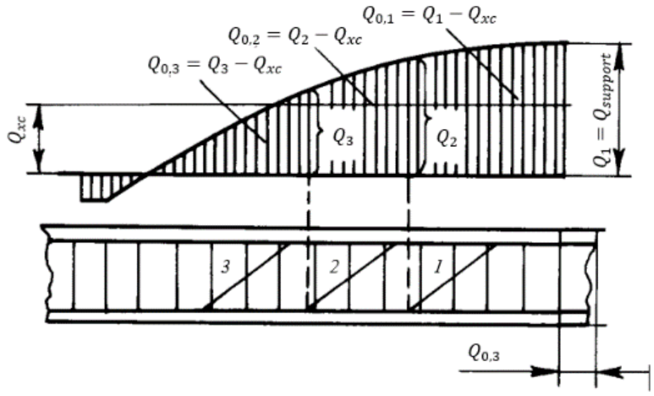

Fig. 1.1.15

.1 for the bends of the first plane, equal to the value of the shear force at the face of the support Q_1;

.2 for the bends of each of the subsequent planes, equal to the value of the shear force in the vertical section that passes through the lower point of the previous bend $Q_{0,1}$, $Q_{0,2}$, $Q_{0,3}$.

1.1.16 The strength of intersectional joints of the hull members shall be checked:

.1 for joints with welded starter bars that are extensions of the main reinforcement and made in accordance with the requirements of Part I "General Requirements for Construction", as for similar cast-in-place members;

.2 for joints on embedded parts made in accordance with the requirements of Part I "General Requirements for Construction", based on the loading diagram of the joint elements with the strength check of fastening of embedded parts and separate anchors taking into consideration Appendix 4.

1.1.17 The strength check of attachments of separate devices, machinery, etc. to reinforced concrete members of the hull shall be made according to the most favorable diagram of their loading. The strength of the connection of separate embedded parts and attachment anchors to reinforced concrete shall be checked taking into consideration Appendix 4.

Where necessary, the strength of the welded joints shall be checked that connect the attached structure to the embedded member.

1.1.18 The strength calculation of hull structures shall be made taking into consideration their own weight calculated for the finally accepted dimensions of the structure and density of reinforced concrete D determined as a sum of the concrete and fittings (steel) weight per unit of structure volume

$$D = m_b + m_s. \quad (1.1.18)$$

A weight of concrete m_b shall be determined experimentally for the initial materials used. When no experimental data is available at the design stage, m_b of heavy-weight concrete may be taken equal to 2300 — 2500 kg/m^3 and m_b of light-weight concrete equal to 1800 — 1900 kg/m^3. When no actual data is available, the following values of m_s may be taken for reinforced concrete structures: 100 kg/m^3 for strips, 150 kg/m^3 for beams, 150 — 200 kg/m^3 for strengthening.

1.1.19 The strength calculations submitted to the Register shall be of checking nature for the finally accepted option. The calculations shall be available for comprehensive check and contain references to sources.

1.1.20 The strength of separate structures, connections and joints may be evaluated experimentally according to the procedure agreed with the Register.

1.2 Design characteristics of materials.

1.2.1 The values of the controlled stresses given in Table 2.1.9 of Part I "General Requirements for Construction" shall be taken as the design resistances of concrete.

For the ultimate limit states, concrete design resistances R_b and R_t are reduced (or increased) by multiplying by the factors given in 2.3 and Tables 1.2.1-1, 1.2.1-2, taking into consideration the specific features of concrete operation conditions, duration of action, repeated load frequency, etc.

Table 1.2.1-1

Item No.	Concrete operation conditions	Factors	
		notation	numerical value
1	Under operating conditions of structures that are favorable for the strength gain of concrete (for example, under water or at ambient air humidity of more than 75 %)	γ_{b1}	1,00
	In other cases		0,90
2	For vertical concreting with concreting lift of more than 1,5 m	γ_{b2}	0,85
3	Freeze/thaw cycles	γ_{b3}	Taken according to 1.2.2
4	For concrete of structures not protected against solar radiation at average monthly temperature of the hottest month > 25 °C	γ_{b4}	

Table 1.2.1-2

Concrete	Concrete moisture conditions	Concrete service factor γ_{b5} for repeated load and stress ratio $\rho = \sigma_{min}/\sigma_{max}$						
		0 — 0,1	0,2	0,3	0,4	0,5	0,6	0,7
Heavy-weight	Natural moisture content	0,75	0,8	0,85	0,9	0,95	1,0	1,0
	Water-saturated	0,5	0,6	0,7	0,8	0,9	0,95	1,0
Light-weight	Natural moisture content	0,6	0,7	0,8	0,85	0,95	0,95	1,0
	Water-saturated	0,45	0,55	0,65	0,75	0,85	0,95	1,0

Notes: 1. Concrete service factors for items 1 and 3 of Table 1.2.1-1 shall be considered in determination of design resistances R_b and R_t, and only when determining design resistance R_b for the remaining items.

2. For structures under repeated load, factor γ_{b1} shall be considered in the strength calculation, and γ_{b5} in the durability and crack-formation calculations according to Table 1.2.1-2.

3. Concrete service factors are introduced independently of each other, but at that, their product shall be not less than 0,45.

1.2.2 When calculating the structures operating in conditions of freeze/thaw cycles, concrete design resistances R_b and R_t shall be additionally multiplied by the service factor determined by the formula

$$\gamma_{bm} = 1 - Kt_b^{\circ} \quad (1.2.2)$$

where K = factor determined in accordance with Table 1.2.2;
t_b° = absolute value of the highest design winter temperature corresponding to the concrete frost resistance grade of the structure under consideration, °C.

Table 1.2.2

Structure category	Value of factor $K \cdot 10^2$ at concrete frost resistance grade				
	100	200	300	400	500
External structures of above-water hull in area of incidental and constant water saturation due to splashing, waves and capillary suction	1,17	0,75	0,5	0,335	0,168
External structures of underwater hull as well as internal structures exposed to incidental freezing	0,667	0,335	0,167	0,084	0

1.2.3 Values of the initial modulus of elasticity of concrete E_b in compression and tension shall be taken according to Table 2.1.9 of Part I "General Requirements for Construction". The design values of the modulus of elasticity are taken by multiplying E_b by a factor taken equal to:

γ_E = 1,08 for concrete with cone slump of 4 — 8 cm;
γ_E = 0,9 for concrete with cone slump more than 8 cm.

For the structures not protected against solar radiation, the specified E_b values shall be taken with a factor of 0,85.

For concrete exposed to freeze/thaw cycles, the E_b values shall be additionally multiplied by the service factor determined by Formula (1.2.2) where factor K is taken in accordance with Table 1.2.3.

Table 1.2.3

Structure category	Value of factor $K \cdot 10^2$ at concrete frost resistance grade				
	100	200	300	400	500
External structures of above-water hull in area of incidental and constant water saturation due to splashing, waves and capillary suction	1,50	1,17	0,83	0,75	0,33
External structures of underwater hull as well as internal structures exposed to incidental freezing	0,67	0,58	0,33	0,17	0

1.2.4 Initial transverse strain coefficient v (Poisson ratio) is taken equal to 0,2 for all types of concrete, and concrete shear modulus G is taken to be equal to 0,4 of the corresponding E_b values specified in Table 2.1.9 of Part I "General Requirements for Construction".

1.2.5 The values of the yield stress of steel for fittings given in Table 2.2.2 of Part I "General Requirements for Construction" are taken as design resistance of bar fittings. Design resistance values of plate fittings are taken in accordance with Part II "Hull" of the Rules for the Classification, and the design resistance values of section reinforcement in accordance with technical conditions and the relevant state standards. During design of the hull structures, the design resistance of fittings shall be taken with consideration for the following factors:

1,0 for bar fittings;

for plate fittings:

0,6 without special treatment of contact surface with concrete and anchors;

0,9 with plate fittings anchored into concrete;

0,9 for rigid reinforcement.

1.2.6 For the structures operating under repeated loads, inelastic deformations of concrete in the compression area shall be considered by the reduction of the concrete elasticity module taking fittings-to-concrete reduction factors v' according to Table 1.2.6.

Table 1.2.6

Concrete compressive strength class	B30	B40	B50	B60
Reduction factor v'	18	12	8,0	5,0

2 STRENGTH CHECK

2.1 Reinforced concrete structures with bar fittings.

2.1.1 The strength of hull reinforced concrete structures in normal sections shall, in general, be determined based on the conditions specified in 1.1.9 of Part II "Making Calculations and Strength Standards". The ultimate (breaking) force in the cross-section of hull members shall be determined in accordance with Appendix 2. At that, when the design external or reduced force that causes bending of the member or eccentric loading of the section acts in the plane of the section symmetry axis and the fittings are concentrated at the member faces perpendicular to the above plane, the calculation of the sections shall be made depending on a ratio between the relative height of the concrete compression area $\xi x/h_0$ (x is the height of concrete compression area) and relative height of the compression area boundary ξ_R, which is assumed equal to:

0,6 when using concrete of class B30;

0,5 when using concrete of class B35 and higher.

2.1.2 The strength of inclined cross-sections of hull reinforced concrete members of constant height under action of transverse force shall, generally, meet the condition given in 1.1.9 of Part II "Making Calculations and Strength Standards".

The ultimate (breaking) force in the inclined cross-section of hull reinforced concrete members shall be determined in accordance with Appendix 2.

2.1.3 In sections inclined to the longitudinal axis of the members operating under action of transverse force and bending moment, the following condition shall be met:

$$Q \leq 0{,}2/R_b b h_0 \qquad (2.1.3)$$

where b = the minimum width of member in cross-section.

2.1.4 For the sections inclined to the longitudinal axis of the member, strength calculation may be omitted when the following condition is met:

$$Q \leq 0{,}56\delta(0{,}5 + 2\xi)R_t b h_0 \qquad (2.1.4\text{-}1)$$

where $0{,}5 < \delta = \frac{2}{1+(M/Qh_0)} < 1{,}5$; (2.1.4-2)

M and Q = forces in normal section that passes through the end of the inclined section in the compression area;

ξ = relative height of compression area of section determined by the formulas

for bent members:

$$\xi = \mu R_s/R_b; \qquad (2.1.4\text{-}3)$$

for eccentric-compression and eccentric-tension members with large eccentricity

$$\xi = \mu R_s/R_b \pm N/(bh_0 R_b); \qquad (2.1.4\text{-}4)$$

sign "+" is taken for eccentric-compression, and sign "−" for eccentric-tension members.

2.1.5 For strip structures under action of forces in the plane of the strip, the structural strength in relation to the action of shear force shall meet the condition

$$\tau_{max} \leq 1{,}85R_t. \qquad (2.1.5\text{-}1)$$

At the same time, the strength of vertical and horizontal fittings shall meet the condition, respectively:

$$F_{sv}R_s + f_{sv}^{'}R_s^{'} \geq K_1\tau_{\max}\sum s; \quad (2.1.5\text{-}2)$$

$$F_{sh}R_s + f_{sh}^{'}R_s^{'} \geq K_2\tau_{\max}\sum s \quad (2.1.5\text{-}3)$$

where F_{sv} and F_{sh} = area of vertical and horizontal fittings, respectively, per 1 running meter of the strip of the design cross-section;

$f_{sv}^{'}$ and $f_{sh}^{'}$ = area of vertical or horizontal fittings, respectively,

$$f_{sv}^{'} = \frac{f_{sv}}{D}\left(\frac{D}{a} - 1\right);\ f_{sv}^{'} = f_{sh}/D; \quad (2.1.5\text{-}4)$$

f_{sv} and f_{sh} = area of longitudinal vertical fittings (one bulkhead, vertical stiffener) or horizontal fittings (side stringer, bulkhead shelf), respectively, per 1 running meter;

D = moulded depth;

a = frame space;

K = factor taken as: $K_1 = 100$, $K_2 = 0{,}5K_1$;

$\tau_{\max}$ = maximum shear stress taken equal to the main tension stress determined for the reduced cross-section of the member;

$\sum s$ = sum of the thicknesses of sides and longitudinal (transverse) bulkheads included in the design cross-section and taking the shear stresses.

2.1.6 The strength calculation of members of reinforced concrete structures under repeated loads (for durability) shall be made by comparing the edge stresses in concrete and tension reinforcement with the corresponding design resistance of concrete and fittings according to the following design conditions:

for concrete $\sigma_b \leq R_b\gamma_{b5}$ and $\sigma_t \leq R_t\gamma_{b5}$; (2.1.6-1)
for fittings $\sigma_s \leq R_s\gamma_s$

where σ_b and σ_t = compression and tension stresses, respectively, in concrete of the reduced section of the member at the most critical type of loading;

σ_s = stresses in tension reinforcement of reduced section;

γ_s = factor determined by the formula

$$\gamma_s = \frac{1{,}8\eta_0\eta_s\eta_c}{1-\rho_s\left(1-\frac{\eta_0\eta_s}{1{,}8}\right)} < 1{,}0 \quad (2.1.6\text{-}2)$$

where η_0, η_s = factors taken according to Tables 2.1.6-1 and 2.1.6-2;

$\rho_s = \sigma_{\min}/\sigma_{\max}$ — asymmetry factor of stress change cycle in fittings;

η_c = factor taking into consideration the presence of welded butt joints along the length of the main reinforcement of reinforced concrete structures taken in accordance with Table 2.1.6-3.

Table 2.1.6-1

Class of fittings	Factor η_0
A-I	0,44
A-II	0,32
A-III	0,28

Table 2.1.6-2

Diameter of bar fittings, mm	up to 20	30	40	Note
Factor η_s	1,0	0,9	0,85	For intermediate values, η_s shall be taken based on linear interpolation

Table 2.1.6-3

Type of welded joint of bar fittings	Factor η_c
Resistance butt welded joint of types:	
RB-M (with machine dressing)	1,0
RB-O (without machine dressing)	0,8
Butt welded joint made by single-electrode bath welding on steel pad with pad length:	
5 and more diameters of the smallest bar to be joined	0,8
1,5 — 3 diameters of the smallest bar to be joined	0,6
Butt welded joint with matched symmetrical pads	0,55

When factor γ_s determined by Formula (2.1.6-2) is greater than unity, the fittings strength shall not be checked for durability. In this case, the edge stresses in concrete and fittings shall be determined in crack-resistant members as for elastic body taking into consideration concrete in the tension area; in non-crack-resistant members, the area and the resistance moment of the reduced section shall be determined not taking into consideration concrete in the tension area.

2.1.7 When the main tension stresses exceed $\gamma_{b5}R_t$ in calculating the strength of inclined cross-sections of members of reinforced concrete structures for durability, their resultant shall be fully taken up by the transverse fittings with stresses in it not more than the design resistance. When the main tension stresses do not exceed $\gamma_{b5}R_t$, the calculation of the inclined sections for durability is omitted.

2.1.8 Calculation of crack resistance (by crack initiation) of reinforced concrete members shall be made when, according to operating conditions, cracks in concrete members are not acceptable, as well as to identify crack initiation areas in statically indeterminate structures during their calculation.

The crack resistance in the sections normal or inclined to the longitudinal axis of the member shall be calculated in each specific case in accordance with Appendix 2.

2.1.9 When calculating the hull structures for crack initiation in the area of intersectional joints, the reduced tensile strength of concrete in the joints of "old" concrete with a "new" one shall be considered by introducing reduction factor ψ to design strength of concrete R_t that shall be determined experimentally. When no experimental data is available, ψ = 0,5 may be taken.

2.1.10 Crack initiation in the sections inclined to the longitudinal axis of the members shall be checked for the outer faces of the member at the points of their intersection with the main central axes of inertia of the reduced section, and for the T-section member, also in the areas of intersection of compression flanges with the web.

2.1.11 For all hull members calculated for strength where crack initiation in their concrete is acceptable, the crack opening shall be checked under constant or constant and random loads.

2.1.12 The hull members are checked for crack opening by comparing the design crack width in the most stretched fibres of the concrete, determined in accordance with Appendix 2 with the crack width given in Table 2.1.12.

At that, the following condition shall be met:

$$a_{cr} \le [\Delta_{cz}] \qquad (2.1.12)$$

where a_{cr} = design crack width determined in accordance with Appendix 2;
$[\Delta_{cz}]$ = allowable crack width determined in accordance with Table 2.1.12.

Table 2.1.12

Hull structural members	Allowable crack width [Δ_{cz}], mm		
	for bending, eccentric-compression and eccentric-tension members with a compression area in the cross-section		for centric- and eccentric-tension members without compression area in the cross-section
	on the side of wetted surface	on the side of non-wetted surface	
Bottom and side plating of underwater hull. Framing plates and girders in ballast compartments	0,10	0,15	0,08
Side plating of above-water hull. Deck plating in open areas	0,08	0,15	0,07
Deck plating in enclosed areas. Bulkhead plating and framing girders in dry compartments	—	0,20	0,15

2.2 Steel-and-concrete and integrated structures.

2.2.1 Steel-concrete and integrated structures where there is a reliable connection of the sheet fittings and rigid reinforcement with the concrete of the reinforced concrete structure that provides their combined action as a whole under all possible forces shall be calculated for strength by taking into consideration the cross sectional area of the steel plating and rigid reinforcement in the calculation formulas both as external and internal reinforcement, respectively. In this context, corrosive wear of the steel shell plating shall be considered in accordance with the requirements of these Rules for steel structures under similar operating conditions.

2.2.2 The strength calculation of integrated structures shall generally be made in accordance with the requirements 1.1.9 of this Part and Appendix 3. The calculation of structures is recommended to be made for the following stages of structure operation:

.1 before the concrete gains strength R_b = 20 MPa, as metal structures for the impact of their own weight, installation and transport loads occurring in the process of construction; in this case, the design resistance of steel shall be taken with a factor of 0,9 for bent structures;

.2 after the concrete has gained its design strength, as steel-concrete with rigid reinforcement (integrated structure) for the full design load. At the same time: in case of asymmetric profile of rigid reinforcement with strengthened tension area, rigid reinforcement shall be replaced in the calculation with symmetric one, and the remaining part of rigid reinforcement in the tension area of section shall be considered together with sheet or bar fittings;

in strength calculation of integrated structures in normal sections at bending, the relative height of compression area ξ determined as a ratio of compression area height x to the effective height of section h_0 taken, in this case, equal to a distance from the compressed edge of concrete to the resultant force in the tension bar fittings, plate fittings and rigid reinforcement shall be less than the greatest (boundary) value of relative height of compression area ξ_R determined according to the formula

$$\xi_R = \xi_0/(1 + \frac{R_s}{400}(1 - 0{,}9\xi_0)) \qquad (2.2.2.2)$$

where ξ_0 = characteristic of compression area of concrete ($\xi_0 = 0{,}85 - 0{,}8R_b \cdot 10^{-2}$);
R_s = the maximum value of the design compressive strength of the steel bar fittings, rigid reinforcement and plate fittings, MPa;
R_b = concrete design compressive strength, MPa.

2.2.3 The strength calculation of steel-concrete structures in general shall be made similarly to the calculation of reinforced concrete structures with bar fittings taking into consideration the external plate reinforcement of the structure in the calculation formulas. In this case, strength calculation of steel-concrete structures in cross-sections inclined to the longitudinal axis may be omitted when the following condition is met

$$Q \leq KR_t bh_0 \tag{2.2.3-1}$$

where K = factor taken equal to 0,75 for heavy-weight concrete;
R_t = design concrete axial tensile strength;
b and h_0 = design geometric characteristics of the member cross-section under consideration.

In case there are no transverse fittings in a steel-concrete structure, the following condition shall be met:

$$Q \leq 1{,}5R_t bh_0^2/C \tag{2.2.3-2}$$

where C = projected length of the cross-section passing through the face of the support on the horizontal line but not more than $2h_0$.

In this case, the right part of this condition shall be not less than $KR_t bh_0$ and shall be taken not more than $2{,}5KR_t bh_0$.

2.2.4 When calculating the inclined cross-sections of integrated structures for transverse force, the concrete strength in the inclined cross-section shall meet the condition

$$Q \leq 0{,}35R_b bh_0 \tag{2.2.4-1}$$

where R_b = design compressive strength of concrete taken in accordance with 2.1.9, Part I "General Requirements for Construction"; in this case, for concrete of class B40 and higher, R_b is taken as for concrete of class B40.

Calculation of inclined cross-sections of integrated structures for transverse force may be omitted when at least one of the conditions is met

$$Q \leq R_t bh_0,\ Q \leq 0{,}8h\delta R_s \tag{2.2.4-2}$$

where h, δ, R_s = height, thickness and design compressive strength of rigid reinforcement in cross-section, respectively.

2.2.5 Calculation of crack resistance and crack width in concrete of integrated structures shall be made in accordance with Appendix 3.

The design crack width shall meet the condition

$$a_{cr} \leq [\Delta_{cz}] \tag{2.2.5}$$

where $[\Delta_{cz}]$ = allowable crack width taken in accordance with Table 2.1.12.

2.2.6 When calculating adhesive strength of steel plate fittings to reinforced concrete strip of steel-concrete and integrated structure, the following conditions shall be generally met:

$$kT \leq \gamma_n N_c + mT_w n; \tag{2.2.6-1}$$

$$kT \leq \gamma_n N_c + mT_{sh} n \tag{2.2.6-2}$$

where k = safety factor;
T = line shear force acting within the section under consideration of unit width and length u of the bent member;

γ_n = reliability coefficient taken as follows:
allowing for adhesion, based on the experimental data approved by the Register; without adhesion γ_n = 0;
N_c = area under consideration ($N_c = \tau_c u$);
m = factor of non-uniformity of the connector action, at that, m = 0,8 for different design of the combined-acting anchors-connectors, m = 1,0 for the same design of the jointly acting anchors;
T_w = shear force corresponding to the concrete strength under the anchors, kN, determined in accordance with 2.2.8;
T_{sh} = shear force taken by a member (vertical cross rod) when it works in shear as rivets or dowels;
n = a number of anchor ties within the considered conventional (design) length u and unit width of the bent member;
u = anchor spacing along the member length.

2.2.7 The shear force acting on the structural members of the plate fittings and the reinforced concrete member of the part of the structure under consideration shall be determined by the relationship

$$T = qS_{pred}u/I_{red} \qquad (2.2.7)$$

where q = shear force acting along the conventional design length u and the unit width of the structural member under consideration taken as the design one;
S_{pred} = static moment of the reduced cross-section of the steel plate attached to reinforced concrete strip in the section of the design member relative to the neutral axis of the reduced cross-section of the member;
I_{red} = inertia moment of the reduced cross-section of the member under consideration.

2.2.8 The shear force on the connector working due to concrete crushing shall be determined by the formulas:
.1 in case of shear connectors:
with connectors in the form of round bars:

$$\text{at } l_{an}/d_{an} \le 4{,}2 \quad T_w = 24 l_{an} b_{an}\sqrt{R_b}\cdot 10^3; \qquad (2.2.8.1\text{-}1)$$

$$\text{at } l_{an}/d_{an} > 4{,}2 \quad T_w = d_{an}^2\sqrt{R_b}; \qquad (2.2.8.1\text{-}2)$$

for inclined bar shear connectors, the shear force per anchor or per leg of a loop anchor shall be determined by the formula

$$T_w = f_s R_s \cos\alpha\,(d_{an}^2\sqrt{R_b}\sin\alpha)\cdot 10^3; \qquad (2.2.8.1\text{-}3)$$

with connectors in the form of rolled section (with linear dimensions in cm)

$$T_w = 0{,}55(h' + 0{,}5\delta)b_{an}\sqrt{R_b}\cdot 10^3; \qquad (2.2.8.1\text{-}4)$$

.2 in case of rigid connectors

$$T_w = 1{,}6 R_b F_{ru} \qquad (2.2.8.2)$$

where l_{an} = length of round bar of shear connector;
F_{ru} = design area of concrete crushing by the connector equal to the vertical projection of the effective area of concrete-to-metal contact;
R_b = concrete design compressive strength;
h' = sum of bending radius and flange thickness of rolled section;
δ = web thickness of rolled section.

2.2.9 The shear force on the connector in the structures operating under variable loads shall be determined by the formula

$$T_w^{\circ} = 1{,}5\gamma_{b5}R_bF_{ru} \quad (2.2.9)$$

where γ_{b5} = factor taken according to Table 1.2.1-2;
R_b = design strength of concrete.

2.3 Composite structures.

2.3.1 When calculating the strength of composite structures, the internal forces (stresses) in the cross-section of the members shall be determined according to the rules of structural mechanics with the conventional substitution of the cross-sectional area of the composite structure for an area equivalent in strength to that of steel determined in accordance with Appendix 1.

2.3.2 Joint efficiency of the steel members of the composite structure and the reinforced concrete structure shall be provided for all shear and tearing forces acting in the joint.

2.3.3 Joint efficiency, which takes the shear forces due to concrete crushing by various connectors (bar fittings, special-purpose anchors, stop plates, etc.) welded to the steel plate (web, flange) shall be checked in accordance with the relevant requirements in 2.2. For the structure with shear connectors shown in Fig. 2.3.3-1, the force on the connector working due to concrete crushing may be determined by the formula

$$T_w = F_{ru}R_b \quad (2.3.3\text{-}1)$$

where F_{ru} = area of concrete crushed by the bar connector perpendicular to the shear force.

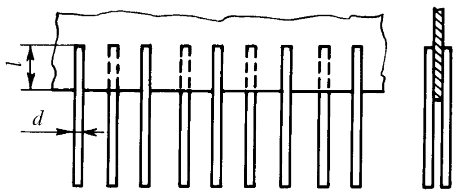

Fig. 2.3.3-1

For the connector shown in Fig. 2.3.3-1, the area of concrete crushed by the bar connector shall be determined by the formula

$$F_{ru} = (1 + 3d)d. \quad (2.3.3\text{-}2)$$

For the connector shown in Figs. 2.3.3-2, *a* and *b*, the area of concrete crushed by the bar connector shall be determined by the formula

$$F_{ru} = 3d^2 \quad (2.3.3\text{-}3)$$

where d = diameter of bar-anchor.

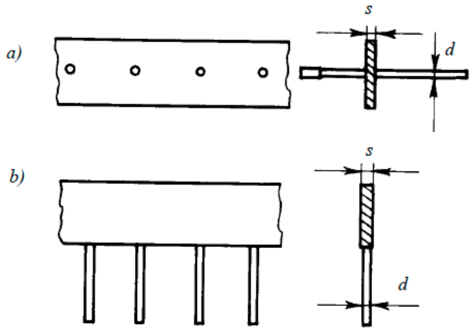

Fig. 2.3.3-2

2.3.4 Tear strength of the joint may be considered sufficient when

$$0{,}5\sum f_{si}R_{si} \geq N \quad (2.3.4\text{-}1)$$

where f_{si} = area of the anchor or the vertical bar fittings out of the set of the anchors (bars) welded to the metal structure that are located along the joint length equal to u;
R_{si} = design compressive strength of steel bar fittings (anchors);
N = tear force determined by the formula

$$N = qu; \quad (2.3.4\text{-}2)$$

here, q = design line force determined by the formula

$$q = QS' s_p / J_{red} \sum s_i \quad (2.3.4\text{-}3)$$

where Q = design shear force acting in the area under consideration;
S' = static moment of the cross sectional area of the metal part of the composite structure relative to the neutral axis of the design cross-section (when the neutral axis is located within the reinforced concrete part of the structure), or the static moment of the reinforced concrete cross-section area reduced to steel that is located below the joint under consideration relative to the neutral axis of the design cross-section (when the neutral axis is located within the metal part of the structure under consideration);
s_p = thickness of the steel plate attached to the reinforced concrete part of the structure in the cross-section under consideration;
$\sum s_i$ = total thickness of all steel plates (webs) attached to the reinforced concrete and taking the shear;
J_{red} = inertia moment of the reduced section;
u = length of the joint section, for which force N is being determined.

In this case, N shall be not less than the value provided by the conditions of welding the ends of the bars (anchors) to the metal structure along the length u.

2.3.5 When, in the joint, the shear is taken by special-purpose connector plates welded to steel structures, the strength of welded connection of the plates to the embedded steel sheets shall be checked as well as the bending strength of the plates.

When exposed to variable loads, the strength of such joints shall be checked in accordance with the procedure approved by the Register.

2.3.6 The strength of joints on the embedded parts exposed to tear force N, shear Q and moment M (or only some of these forces) shall be checked in accordance with Appendix 4, provided the structural members of the embedded part and welding of its elements meet the requirements of Part I "General Requirements for Construction".

2.3.7 When the design of joint of the reinforced concrete members to the metal ones differs from the designs under consideration and has a specific loading diagram, then its strength shall be evaluated taking into consideration the loading characteristics of the separate members of the composite structure. In this case, allowable tensile stresses for steel may be taken equal to 0,5R_s, and allowable crushing and compressive stresses for concrete to 0,5R_b.

In critical cases, additional experimental check of the strength of these joints is required.

PART III. SPECIFIC CONSTRUCTION OF PRESTRESSED REINFORCED CONCRETE HULLS

1 GENERAL

1.1 Prestressed reinforced concrete may be used for the manufacture of reinforced concrete hulls of ships and floating docks, as well as reinforced concrete parts of ships and floating docks of composite construction or their separate members.

1.2 Prestressing of structures may be both general and local and shall be done primarily for the most stressed tension reinforced concrete members and assemblies, as well as reinforced concrete strips of the shell plating and framing girders.

It is recommended that pre-reduction be provided for intersectional attachments, which, with sufficient reduction over the entire section height, can be designed without welding of starter bars.

It is not recommended that prestressing be provided in the steel members of the hulls.

1.3 Prestressing of the hull and intersectional joints shall be done by pretensioning of high-strength bar fittings, strands or bundles placed inside thickened strips of plating, in longitudinal girders or reinforced hull members (deck stringer, bilge, bulkhead sections adjacent to the deck or bottom), as well as in reinforced intersectional joints.

1.4 For prestressed structures, heavy-weight concrete of class not lower than B40 or light-weight (keramzite) concrete of class not lower than B30 shall be used that is prepared with sulfate-resisting Portland cement.

The requirements for strength, watertightness, frost resistance and durability of concrete used to manufacture prestressed structures shall be the same as for the concrete of hull structures made of normal (non-stressed) reinforced concrete.

1.5 To fill the channels with prestressed reinforcement, fine-grained concrete of class not lower than B40 shall be used that provides high-quality filling of the channel with the accepted method of injection.

1.6 For prestressed reinforcement of hull prestressed structures, the following may be used upon agreement with the Register:

.1 high-strength reinforcement bundles and strands;
.2 bars of heat-treated steel for fittings;
.3 bars of hot-rolled steel for fittings of classes A-II and A-III.

1.7 The pretensioned reinforcement shall be located in the dedicated channels or grooves with a diameter (or width) not less than the diameter of a bar, bundle or strand placed therein plus 20 mm. Installation is allowed of the above fittings outside, in the areas of intersection of the framing girders to the plating when, by means of the dedicated fittings and grouting concrete, the combined action will be provided for the tensioned fittings with the girder or plate.

1.8 Thickness of the protective concrete layer of prestressed reinforcement shall be not less than its diameter and not less than that required for non-stressed reinforcement under similar conditions.

Distance from the channel surface to the outer surface shall be at least 40 mm, and the thickness of the concrete layer grouting the prestressed reinforcement located near the girder or strip shall be not less than 20 mm.

The clear distance between the channels shall be not less than the channel diameter and, in any case, not less than 50 mm.

1.9 All fittings subject to prestressing shall be securely fastened at the ends with the dedicated anchors embedded in the strengthened hull members that are provided with additional transverse fittings under the anchors.

1.10 The process for the construction of the hull using prestressed reinforced concrete shall be agreed with the Register and shall be subject to the technical supervision at all stages of construction.

The process part of the design shall contain the detailed information on the methods of fittings tensioning and control of the values of their tensioning, on the anchoring of the fittings ends and the methods of fixing the anchors, on the grouting of tensioned fittings located in channels and grooves and the quality control of its performance, as well as on the control of values of concrete prestressing in the hull structures and in the intersectional joints.

1.11 By the time when the prestressing force is transferred to the concrete, its strength shall be not less than 70 % of the design concrete strength.

To accelerate the curing of concrete in prestressed structures, it may be steamed, which is done taking into consideration Section 4, Part I "General Requirements for Construction".

1.12 The grouting of the prestressed reinforcement located in the channels shall be done with the control of filling all sections of the channel along its length. The grouting of the same fittings placed in the grooves shall be done with intensive compaction of concrete by vibration.

Tensioned fittings placed on the surface (refer to 1.7) shall be grouted with concrete after thorough notching of the old concrete in the areas of its contact with a new one.

1.13 Reinforcing during manufacture of prestressed reinforcement members shall be carried out taking into consideration the specific connection (including welding) of high-strength bars and wires.

2 GENERAL INSTRUCTIONS FOR CALCULATION

2.1 Structures made of prestressed reinforced concrete shall be checked by calculation for strength and crack resistance, as well as for providing the sufficient prestressing in concrete and reinforcement for the adopted method of hull construction, including:

.1 at design operating loads combined with concrete and bar fittings prestressing;

.2 at concrete prestressing combined with the forces that are possible at transportation and installation during construction;

.3 at concrete prestressing.

2.2 The main calculation for ship structures of prestressed reinforced concrete is the calculation for crack resistance. This calculation is used to check the absence of cracks in the structure when it is exposed to design loads.

Along with this calculation, the strength of concrete shall be checked in the compression area, strength of fittings in the tension area, and safety factor of the entire cross-section shall be evaluated.

2.3 Calculations for crack resistance and strength of prestressed structures shall be made according to the procedure approved by the Register.

The safety factors for crack initiation and strength of the sections shall be not less than those given in Table 2.3.

Table 2.3

Members to be calculated	Considered load		
	constant	constant and random, as well as random only	emergency
Members contributing to overall strength or to the overall and local strength simultaneously	1,25/1,8	1,20/1,7	–/1,5
Members contributing to local strength only	1,15/1,7	1,1/1,5	–/1,3
Note. Numerator is the safety factor for crack initiation, denominator is the strength factor. Sign "–" means that the factor is not rated.			

Stresses in the compression area of concrete due to the combined action of prestressing and design load shall not exceed 0,6R_b; the main tension stresses 0,8R_t; the main compressive stresses 0,5R_b.

2.4 Prestressed reinforced concrete structures shall be checked for crack opening (where allowed) in accordance with 2.1, Part II "Making Calculations and Strength Standards" taking into consideration the effect of fittings prestressing according to the procedure specified in 2.3.

2.5 All prototype ships and facilities constructed with prestressed reinforced concrete, as well as individual ships of a series and facilities shall be subjected to the strength tests according to the program agreed with the Register.

APPENDIX 1

DETERMINATION OF INTERNAL FORCES IN HULL MEMBERS

1.1. The design longitudinal forces in the hull cross-section members due to the total bending moment shall be determined without taking into consideration the concrete in the tension area by the formula

$$N = MS_{red}/J_{red} \quad (1.1)$$

where M = design bending moment in the hull cross-section;
S_{red} = static moment of the reduced section of the member under consideration relative to the neutral axis of the hull cross-section;
J_{red} = intrinsic inertia moment of the reduced hull cross-section.

1.2. Main tensile (compression) stresses in the hull structural members parallel to the plane of bending moment action (sides, longitudinal and transverse bulkheads), in longitudinal bending shall be determined with due regard to concrete action in the tension area by the formula

$$\sigma_m = QS_{red}/(J_{red}\sum h) \quad (1.2\text{-}1)$$

where σ_m = main stresses equal to the shear stresses on the neutral axis;
Q = design shear force due to longitudinal bending of the hull;
S_{red} = static moment relative to the neutral axis of the part of the reduced hull cross-section located on the same side of the neutral axis;
J_{red} = intrinsic inertia moment of the reduced area of the design cross-section of the hull;
$\sum h$ = total thickness of the members (side plating, longitudinal and transverse bulkheads) parallel to the plane of bending moment action, which take the main stresses at the level of the neutral axis.

When calculating J_{red} and S_{red}, the reduced area of the design cross-section of the hull shall be determined by the formula

$$F_{bred} = \sum(f_b + f_s E_s/E_b); \quad (1.2\text{-}2)$$

$$F_{sred} = \sum(f_s + f_b E_b/E_s) \quad (1.2\text{-}3)$$

where F_{bred} and F_{sred} = area of the design cross-section of the hull reduced to concrete or reinforcement (steel), respectively;
f_b and f_s = cross-sectional area of the concrete or reinforcement (steel) of the structural member under consideration, respectively.

At the same time, when the steel structural members included in the design cross-section may lose stability, their corresponding cross-sectional area shall be included in the reduced area taking into consideration the reduction factor.

1.3 The design forces due to local loads shall be determined in accordance with the general rules of structural mechanics for elastic systems, taking into consideration the following requirements:

.1 depending on the hull design, the hull framing girders shall be calculated as part of the frames, strips or as multi-span or separate girders, taking into consideration the conditions of fixing on the supports.

In this case, the inertia moments of the structural members' cross-sections to determine a ratio of their stiffness shall be determined on the assumption of elastic action of the entire concrete cross-section of these structural members without taking into consideration the fittings.

When calculating the frames, a length of the design spans may be set at the level of the neutral axis position of the concrete section of the girder determined with consideration to the effective flange;

.2 rectangular strips supported on four or three edges shall be calculated as strip girders with a span equal to the smaller side of the strip when the aspect ratio is more than 2:1. When the aspect ratio is equal to or less than 2:1, the calculation shall be made according to the formulas of thin isotropic plates.

Strips supported on two opposite edges shall be calculated as strip girders with a span equal to a distance between supports;

.3 when calculating multi-span girders, the following values shall be taken as design span l depending on support width b (refer to Fig. 1.3.3, *a*):

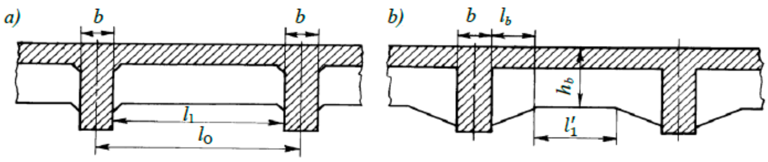

Fig. 1.3.3

$l = l_0$ at $b \leq 0{,}05 l_0$;

$l = 1{,}05 l_1$ at $b > 0{,}05 l_0$

where l_0 = distance between the axes of supports;

l_1 = clear distance between the inner faces of the supports

In case of inexplicit supports or reinforced haunches taken into consideration in the calculation that have an incline of not less than 1:3, the design span shall be taken equal to the greatest of the following values (refer to Fig. 1.3.3, *b*):

$l_1' + h_b$ or $1{,}05 l_1'$, but not more than $l_1' + b + 2l_r$ (1.3.3)

where l_1' = distance between the beginning of the haunches;
h_b = girder height (strip thickness) in the middle of the span;
l_r = length of haunch.

1.4 The values of the main tensile stresses in the structural member concrete σ_m shall be determined for the reduced cross-section of the structural member assuming the elastic action of concrete by the formula

$$\sigma_m = \sigma_x/2 + \sqrt{(\sigma_x/4)^2 + \tau^2} \quad (1.4\text{-}1)$$

where σ_x and τ = normal and shear stresses in concrete, respectively:

$$\sigma_x = My/i_{red} \pm N/f_{red} \quad (1.4\text{-}2)$$

$$\tau = QS_{red}/(i_{red} b); \quad (1.4\text{-}3)$$

for rectangular section

$$\tau = [Q/(0{,}9h_0)] \cdot 10^2, \text{ kN/m}^2; \quad (1.4\text{-}4)$$

f_{red}, i_{red} = area and inertia moment of the member section reduced to concrete relative to its centre of gravity;
S_{red} = static moment of a part of reduced cross-section that is located on the same side of the axis, at which level shear stresses are determined;
y = distance from the centre of gravity of the reduced section to the line, at which level the shear stresses are determined;
b = width of the section at the same level.

In Formula (1.4-1), tensile stresses shall be introduced with sign "+", and compressive stresses with sign "–"; in Formula (1.4-2), sign "+" shall be taken for eccentric-tension members, and sign "–" for eccentric-compression members.

APPENDIX 2

DETERMINATION OF DESIGN CHARACTERISTICS OF REINFORCED CONCRETE STRUCTURAL CROSS-SECTIONS

2.1 Determination of ultimate (breaking) forces in normal structural cross-sections.

2.1.1 In axial compression

$$N_u = \varphi[f_b R_b + (f_s R_s + f_s' R_s')] \quad (2.1.1)$$

where φ = stress reduction factor taken from Table 2.1.1 depending on the flexibility of the member l_0/r (for rectangular section l_0/b);

l_0 = design length of member, cm;

r = minimum radius of gyration for concrete section of member, cm;

b = minimum dimension of the rectangular cross-section of member, cm.

Table 2.1.1

l_0/b	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
l_0/r	35	42	48	55	62	69	76	83	90	97	104	111	118	125	132	139
Basic load	1,0	0,96	0,92	0,88	0,84	0,79	0,75	0,70	0,65	0,61	0,56	0,51	0,47	0,42	0,38	0,34
Constant load	1,0	0,96	0,92	0,87	0,79	0,71	0,64	0,58	0,51	0,45	0,39	0,34	0,29	0,25	0,21	0,17

Design length of a member l_0 shall be determined by multiplication of its geometrical length by a factor, which depends on a degree of restraint and displacement of the member ends and is taken equal to:

0,5 at full restraint of both ends;

0,7 at full restraint of one end and hinge-fixed attachment of the other end, and also at partial restraint of the ends;

1,0 when both ends are hinged-fixed.

2.1.2 In axial tension

$$N_u = f_s R_s + f_s' R_s'. \quad (2.1.2)$$

2.1.3 In bending:

.1 for rectangular section of member

$$M_u = R_b b x (h_0 - 0{,}5x) + f_s' R_s' (h_0 - a'); \quad (2.1.3.1\text{-}1)$$

$$x = (f_s R_s + f_s' R_s')/(R_b b). \quad (2.1.3.1\text{-}2)$$

Height of the concrete compression area x shall meet the following conditions:

$$x \le \xi_R h_0 \quad (2.1.3.1\text{-}3)$$

where for ξ_R, refer to 2.1.1, Part II "Making Calculations and Strength Standards";

$$x \ge 2a'. \quad (2.1.3.1\text{-}4)$$

At $x < x_0 \le 2a'$ where x_0 is the height of the compression area determined without regard to the compression reinforcement, the compression reinforcement is not considered in the calculation and the condition ($x \ge 2a'$) is ignored.

At $x < 2a' < x_0$, an area of the compression reinforcement introduced into the calculation shall be determined by the formula

$$f_s' = f_s - (R_b b)R_s)2a', \quad (2.1.3.1\text{-}5)$$

design breaking force shall be determined by the formula

$$M_u = 2R_b ba'(h_0 - a') + f_s' R_s'(h_0 - a'); \quad (2.1.3.1\text{-}6)$$

.2 for a T-section with a face plate in the tension area: in the same way as for the rectangular section of the member with a width equal to rib width b;

.3 for T-section with face plate in compression area:

at $0{,}1h_0 \le h_p \le 0{,}2h_0$ (2.1.3.3-1)

$$M_u = f_s R_s[h_0 - (h_p/2)]; \quad (2.1.3.3\text{-}2)$$

at $h_p > 0{,}2h_0$ and $f_s R_s \le R_b b_p h_p + f_s' R_s'$, as for rectangular section with dimensions $b_p \times h$;

at $h_p > 0{,}2h_0$ and $f_s R_s > R_b b_p h_p + f_s' R_s'$ by the formula

$$M_u = R_b[bx(h_0 - \frac{x}{2}) + 0{,}8h_p(b_p - h_p)(h_0 - \frac{h_p}{2})] + f_s' R_s'(h_0 - a') \quad (2.1.3.3\text{-}3)$$

where $x = [(f_s - f_s')R_s - 0{,}8(b_p - b_b)h_p R_b]/(R_b b)$. (2.1.3.3-4)

At that, the static moment of the cross sectional area of the concrete compression area S_b relative to the centre of gravity of the tension reinforcement section f_s shall be $S_b \le 0{,}8S_0$ where S_0 is the static moment of the effective section area relative to the centre of gravity of the reinforcement section f_s.

2.1.4 For eccentric-compression members:

.1 rectangular section:

at $x \le \xi_R h_0$ (eccentric compression with large eccentricity)

$$N_u = R_b bx - (f_s - f_s')R_s \quad (2.1.4.1\text{-}1)$$

where

$$x = (h_0 - e) + \sqrt{(h_0 - e)^2 + [2(f_s e \pm f_s' e')R_s]/(R_b b)}; \quad (2.1.4.1\text{-}2)$$

e and e' = distances from the application point of force N to the centre of gravity of the tension and compression reinforcement sections, respectively (determined by the formulas given below in this Appendix). The sign "–" before the second term of the radical expression shall be taken in case when the application point of force N is beyond the centres of gravity f_s and f_s'.

Height of the compression area shall meet the following conditions:

$$x \le \xi_R h_0 \quad (2.1.4.1\text{-}3)$$

where for ξ_R, refer to 2.1.1 Part II "Making Calculations and Strength Standards";

$$x \ge 2a'. \quad (2.1.4.1\text{-}4)$$

At $x < x_0 \le 2a'$ compression reinforcement is ignored in the calculation, and the condition ($x \ge 2a'$) is not taken into consideration.

At $x < 2a' < x_0$, the area of the compression reinforcement introduced into the calculation and the design breaking force shall be determined, respectively, by the formulas:

$$f_s'' = [f_s R_s e - 2R_b bae']/(R_s e'); \quad (2.1.4.1\text{-}5)$$

$$N_u = 2R_b ab - (f_s - f_s')R_s. \quad (2.1.4.1\text{-}6)$$

At $x > \xi_R h_0$ (eccentric compression with small eccentricity)

$$N_u = [f_s' R_s'(h - a') + 0{,}4 R_b b h_0^2]/e. \quad (2.1.4.1\text{-}7)$$

In this case when the application point of force N is between centre of gravity of reinforcement sections f_s and f_s', the following condition shall be met:

$$kNe' \le f_s R_s (h - a') + 0{,}4 R_b f_b b (h - a')^2; \quad (2.1.4.1\text{-}8)$$

.2 T-section:

with the effective flange located in the tension or least compression area, the same as for rectangular members with a width equal to rib width b;

with the effective flange located in the most compression area:

at $h_p > 0{,}1 h_0$ and $x < h_p$ (where x shall be determined by Formula (2.1.4.1-2) at $b = b_p$), the same as for rectangular section with a width equal to the width of the effective flange b_p;

at $h_p > 0{,}1 h_0$ and $x < h_p$ (where x shall be determined by Formula (2.1.4.1-2) at $b = b_p$) and at $x \le \xi h_0$ where x shall be determined by the formula

$$x = (h_0 - e) + \sqrt{(h_0 - e)^2 + \frac{2(f_s e \pm f_s' e)R_s + 0{,}8 R_b (b_p - b) h_p (h_0 - e h_p/2)}{R_b b}} \quad (2.1.4.2\text{-}1)$$

(the sign "−" before the second term of the radical expression shall be taken in the case where the application point of force N is beyond the centre of gravity f_s and f_s')

$$N_u = R_b b x + 0{,}8 R_b (b_p - b) h_p - (f_s - f_s') R_s; \quad (2.1.4.2\text{-}2)$$

at $h_p > 0{,}1 h_0$ and $x > h_p$ (where x shall be determined by Formula (2.1.4.1-2) at $b = b_p$) and at $x > \xi_R h_0$ where x shall be determined by Formula (2.1.4.2-1))

$$N_u = \frac{1}{e}\left\{R_b (b_p - b) h_p (h_0 - \frac{h_p}{2}) + 0{,}5 b h_0^2] + R_s' f_s' (h_0 - a')\right\}. \quad (2.1.4.2\text{-}3)$$

At that, the following condition shall be also met

$$kNe' \le R_b[(b_p - b) h_p (\frac{h_p}{2} - a) + 0{,}5 b (h - a')^2] + R_s f_s (h_0 - a'). \quad (2.1.4.2\text{-}4)$$

In the above formulas:

a distance from the application point of force N to the centre of gravity of reinforcement section f_s shall be determined by the formula

$$e = \frac{M}{N} + c - a \quad (2.1.4.2\text{-}5)$$

where c = a distance from the centre of gravity of the geometric cross-section to the tension or least compression edge (for plates, $c = 0{,}5 h_p$);

a distance from the application point of force N to the reinforcement centre of gravity f_s' shall be determined by the formulas:

$$e' = \frac{M}{N} - c' + a' \text{, if } \frac{M}{N} > c' - a' \quad (2.1.4.2\text{-}6)$$

or

$$e' = c' - \frac{M}{N} - a' \text{, if } \frac{M}{N} \le c' - a' \quad (2.1.4.2\text{-}7)$$

where c' = a distance from the centre of gravity of the geometric cross-section to the compression or most compression edge (for plates, $c = 0{,}5 h_p$).

When calculating the eccentric-compression members, the effect of their flexibility shall be taken into consideration:

for sections of any shape at $l_0/r > 35$;

for rectangular sections at $l_0/h > 10$.

The member flexibility in the plane of moment action shall be taken into consideration by multiplying design eccentricity $e_0 = M/N$ by factor η determined by the formulas:

for sections of any shape

$$\eta = \frac{1}{1 - \frac{kN}{5270 R_b F}\left(\frac{l_0}{h}\right)^2}; \qquad (2.1.4.2\text{-}8)$$

for rectangular sections

$$\eta = \frac{1}{1 - \frac{kN}{440 R_b F}\left(\frac{l_0}{h}\right)^2}; \qquad (2.1.4.2\text{-}9)$$

where l_0 = design length of the member determined in accordance with 2.1.1;
r = minimum radius of inertia of the member cross-section;
F = cross-sectional area of member;
k = safety factor taken from Table 1.1.9.4, Part II "Making Calculations and Strength Standards".

2.1.5 For eccentric-tension members:

.1 rectangular and T-section at $e < c$ (eccentric tension with small eccentricity), respectively:

$$N_u = \frac{1}{e} f_s R_s (h_0 - a'); \qquad (2.1.5.1\text{-}1)$$

$$N_u = \frac{1}{e} f_s' R_s' (h_0 - a') \qquad (2.1.5.1\text{-}2)$$

where *c, e* and *e'* — refer to below.

When estimating the load-carrying capacity in this case, the expression with the lower value of the right-hand side shall be used;

.2 rectangular as well as T-section with the effective flange in the tension area:

at $e > c$ (eccentric tension with large eccentricity)

$$N_u = R_s (f_s - f_s') - R_b b x \qquad (2.1.5.2\text{-}1)$$

where $$x = (h_0 - e) - \sqrt{(h_0 + e)^2 + \frac{2R_s(f_s' e' - f_s e)}{R_b b}}, \qquad (2.1.5.2\text{-}2)$$

at that, the conditions $x \le \xi_R h_0$ and $x \ge 2a'$ shall be met.

At $x < x_0 \le 2a'$, where x_0 is the height of the concrete compression area determined without taking into consideration the compression reinforcement, the compression reinforcement shall not be taken into consideration in the calculation and the above condition $x \ge 2a'$ is ignored.

At $x < 2a' < x_0$, an area of the compression reinforcement introduced into the calculation shall be determined by the formula

$$f_s' = [f_s R_s e - 2 R_b a' b e']/(R_s\, e'), \qquad (2.1.5.2\text{-}3)$$

and the design ultimate force of the member section N_p shall be determined by the formula

$$N_u = R_s (f_s - f_s') - 2 R_b a' b; \qquad (2.1.5.2\text{-}4)$$

.3 T-section with the effective flange in the compression area:

at $e > c$; $h_p > 0{,}1h_0$ and $x < h_p$ as for a rectangular section with a width equal to the width of the effective flange b_p (c — see below; x shall be determined by Formula (2.1.5.2-2));

at $e > c$ (c — refer to below); $h_p > 0{,}1h_0$ and $x > h_p$ where x shall be determined by Formula (2.1.5.2-2) at $b - b_p$

$$N_u = R_s(f_s - f_s') - 0{,}8R_b(b_p - b)h_p - R_b bx \quad (2.1.5.3\text{-}1)$$

where $$x = (h_0 + e) - \sqrt{(h_0 + e)^2 + \frac{2[R_s(f_s'e' - f_s e) + 0{,}8R_b(b_p - b)h_p(h_0 + e - h/2)]}{R_b b}}. \quad (2.1.5.3\text{-}2)$$

For this case:

distance from the application point of force N from the centre of gravity of the reinforcement section f_s shall be determined:

for large eccentricity by the formula

$$e = \frac{M}{N} - c + a; \quad (2.1.5.3\text{-}3)$$

for small eccentricity by the formula

$$e = c - \frac{M}{N} - a \quad (2.1.5.3\text{-}4)$$

where c = at large eccentricity, it shall be taken equal to a distance from the centre of gravity of geometric section to the tension edge, and at small eccentricity, from the centre of gravity of the entire reinforcement area to the most tension edge.

A distance from the application point of force N to the centre of gravity of the reinforcement section shall be determined by the formula

$$e' = \frac{M}{N} - c' + a' \quad (2.1.5.3\text{-}5)$$

where c' = at large eccentricity, it shall be taken equal to a distance from the centre of gravity of geometric section to the compression edge, and at small eccentricity, from the centre of gravity of the entire reinforcement area to the least tension edge;

a' = a distance from the centre of gravity of the compression reinforcement section to the compression or least tension edge.

2.2 Determination of ultimate (breaking) force in structures in inclined sections.

2.2.1 The design breaking force in the inclined section of the member shall be determined by the formula

$$Q_u = R_s(\sum f_0 \sin\alpha + \sum f_x) + Q_b \quad (2.2.1)$$

where $\sum f_0$ = sectional area of all bent bars located in the same plane inclined to the member axis at angle α that intersects the inclined section under consideration;

$\sum f_x$ = sectional area of all cross rods located in the same plane normal to the member axis that intersects the inclined section under consideration;

Q_b = projection of the ultimate force in the concrete of the inclined section on the normal to the longitudinal axis of the member determined in accordance with 2.2.2.

2.2.2 A projection of the ultimate force in the concrete of any inclined section on the normal to the longitudinal axis of the member shall be determined by the formula

$$Q_b = (0{,}16 R_b b h_0^2)/c_0 \qquad (2.2.2\text{-}1)$$

where c_0 = length of the projection of the least favorable inclined section on the longitudinal axis of the member shall be calculated by the formula

$$c_0 = \sqrt{(0{,}16 R_b b h_0^2)/q_x} \qquad (2.2.2\text{-}2)$$

q_x = ultimate force in the cross rods per unit length of the member,

$$q_x = R_s f_x n / a_x; \qquad (2.2.2\text{-}3)$$

f_x = section of one leg of transverse bar (clamp);
n = a number of legs of cross rods in the same section of the member;
a_x = distance between the cross rods along the member length.

2.2.3 The design breaking shear force in the inclined section in the absence of inclined fittings shall be determined by the formula

$$Q_u = \sqrt{0{,}6 R_b b h_0^2 q_x} - q_x a_x,\ kN. \qquad (2.2.3)$$

For the members uniformly loaded from the side of the compression area, the design breaking shear force may be determined with allowance for a part of this load applied to the member within a length of the inclined section projection. In this case, in Formulas (2.2.2-2) and (2.2.3) instead of the value q_x, $(q_x + q)$ shall be introduced where q is the intensity of the external uniformly distributed load.

2.3 Calculation of crack resistance and determination of a crack width in the tension area of structures.

2.3.1 The forces causing crack initiation in concrete of reinforced concrete hull structures shall be determined according to the following dependences:

.1 in axial tension

$$N_{cr} = \gamma_d R_t F_{red}; \qquad (2.3.1.1)$$

.2 in bending:

$$M_{cr} = \gamma_r R_t W_{red} \qquad (2.3.1.2\text{-}1)$$

where F_{red} and W_{red} = area and the moment of resistance of the reduced section of the member;
γ_d = factor taking into consideration the effect of a number of fittings and dispersion of reinforcement on the crack resistance of the member;

$$\gamma_d = 1 + \mu^2 v^2 \frac{100}{d} < 2 \qquad (2.3.1.2\text{-}2)$$

(here μ = section reinforcement factor;
v = ratio of modulus of elasticity of reinforcement and concrete;
d = bar fittings diameter, mm);
γ_r = factor taking into consideration the inelastic action of the concrete in the tension area);

$$\gamma_r = 1 + \frac{C + 2a}{h_t} < 2 \qquad (2.3.1.2\text{-}2)$$

(here C = parameter determined according to Table 2.3.1.2;
h_t = height of the tension area of the reduced section).

Table 2.3.1.2

Concrete compressive strength class	B30	B40	B50
C, cm	5,5	4,4	3,0
N o t e . For intermediate concrete compressive strength classes, parameter C shall be taken by linear interpolation.			

2.3.2 Crack width for cracks normal to the axis of reinforced concrete members shall be determined by the formula

$$a_{cr} = 20\delta\rho\frac{\sigma_s-\sigma_{s,bg}}{E_s}(3{,}5-100\mu)^3\sqrt{d} \quad (2.3.2\text{-}1)$$

where δ = factor:
for centric-tension members shall be taken equal to 1,2;
in other cases δ = 1;
ρ = factor:
for periodic-profile bars shall be taken equal to 1,0;
for plain bars 1,3;
σ_s = stress in the tension reinforcement determined by Formula (2.3.3-1);
$\sigma_{s,bg}$ = initial tensile stress in the fittings due to concrete swelling. For structures under water, $\sigma_{s,bg}$ = 20 MPa, for structures exposed to prolonged drying including that during construction, $\sigma_{s,bg}$ = 0;
μ = section reinforcement factor determined by the formulas given below and taken, in all cases, not more than 0,02:
for strips $\mu = f_s/(bh_0)$;
for girders with face plate in the compression area
$\mu = f_s/(b_b h_0)$; (2.3.2-2)
girders with face plate in the tension area
$\mu = f_s/[b_b h_b + b_p(h_0 - h_p)]$; (2.3.2-3)
b_b = width of girder rib;
b_p = width of effective flange;
h_b = height of rib;
d = diameter of bars in tension reinforcement. For different diameters of bars, it shall be taken:

$$d = \sum_1^k n_i d_i^2 / (\sum_1^k n_i d_i); \quad (2.3.2\text{-}4)$$

n = a number of bars of the same diameter.

N o t e s : 1. For girders with a flange in the tension area, area f_s includes the reinforcement of the rib and strip located within a width of the effective flange.

2. For the plates that have transverse reinforcement of diameter $d_1 > 0{,}07h_p$ in the tension area placed at intervals t and parallel to the cracks, a distance between the cracks shall be taken equal to t, provided that $0{,}7l_t \le t \le 1{,}3l_t$.

2.3.3 Stresses in the reinforcement in the calculation of crack width shall be determined by the following formula:

$$\sigma_s = \varphi_0\sigma_0 + \varphi_b\sigma_b \quad (2.3.3\text{-}1)$$

where σ_0 = tensile stress due the axial force,
$\sigma_0 = N/(f_s + f_s')$; (2.3.3-2)
N = axial tension force;
$(f_s + f_s')$ = total cross-sectional area of the fittings in the cross-section of the member;
σ_b = tensile stresses in the fittings due to the bending moment,

$$\sigma_b = \theta M/(f_s h_0 \eta); \quad (2.3.3\text{-}3)$$

θ = factor taking into consideration a variation of the moment in the area between the cracks: for the support sections of the strips shall be taken equal to 0,8, and in other cases, 1,0;
M = bending moment in the section under consideration;

f_s = sectional area of the fittings in tension due to the bending moment M;
h_0 = effective height of the section;
η = factor: for plates and T-girders with the face plate in the tension area, shall be taken equal to 0,85; for T-beams with the effective flange in the compression area, 0,90;
φ_0 and φ_b = factors taken according to Table 2.3.3.

Table 2.3.3

Nature of load	Axial tension, φ_0	Bending, φ_b
Random	0,65	0,8
Constant	0,8	1,0
Repeated and vibration	0,95	1,2

APPENDIX 3

DETERMINATION OF CROSS-SECTION DESIGN CHARACTERISTICS OF INTEGRATED STRUCTURES

3.1 Determination of ultimate (breaking) forces in structures at normal sections.

3.1.1 In axial compression

$$N_u = \varphi[\sum R'_{si}f'_{si} + (R_{sr} - R_b)F_{sr} + R_b f_b] \quad (3.1.1)$$

where φ = stress reduction factor (refer to 2.1.1 of Appendix 2).
$\sum R'_{si}f'_{si}$ = sum of products of the cross sectional areas of the compression bar and sheet fittings and their design compressive strength;
F_{sr} and f_b = cross sectional area of the rigid reinforcement and concrete in cross-section of the member, respectively;
R_{sr} and R_b = design compressive strength of the rigid reinforcement and concrete, respectively.

3.1.2 In axial tension

$$N_u = \sum R_{si}f_{si} + (R_{sr} - F_{sr}) \quad (3.1.2)$$

where $\sum R_{si}f_{si}$ = sum of the products of cross sectional areas of the tension bar and sheet fittings and their design compressive strength (for other symbols, refer to 3.1.1).

3.1.3 In bending

$$M_u = R_b\frac{bx^2}{2} + (R_{sr} - R_b)[W_v + 0{,}5(h_1 - x)^2\delta] + \sum R_{si}f_{si}(h_1 - x) + \sum R'_{si}f'_{si}(x - a'); \quad (3.1.3\text{-}1)$$

$$x = \frac{(R_{sr}-R_b)h_1\delta + \sum R_{si}f_{si} + \sum R'_{si}f'_{si}}{R_b b + 2(R_{sr}-R_b)\delta} \quad (3.1.3\text{-}2)$$

where W_v = plastic moment of compressive strength of the rigid reinforcement ($W_v = 1{,}17W$);
δ = web thickness of the rigid reinforcement profile;
h_1 = distance from the centre of gravity of the tension bars and sheet fittings to the compression face of the member section.

In this case, the conditions shall be met:

$x \leq \xi_R h_0$ (refer to 2.2.2, Part II "Making Calculations and Strength Standards"); (3.1.3-3)
$\bar{a} \geq 0{,}25x$ (3.1.3-4)

where $\bar{a}$ = distance from the free upper edge of the rigid reinforcement profile to the neutral axis of the section. For other symbols, refer to 3.1.1 and 3.1.2 of the Appendix.

3.1.4 In the case of eccentric tension, the ultimate (breaking) force in the section of eccentric-tension members at $x \leq \xi_R h_0$ and $\bar{a} > 0{,}25x$ shall be determined by the conditions:

$$N_u = 2(R_{sr} - R_b)(0{,}5h - x)\delta - R_b bx + \sum R_{si}f_{si} - R'_{si}f'_{si}; \quad (3.1.4\text{-}1)$$

$$Ne + (R_{sr} - R_b)[W_v + 2\delta(0{,}5h - x)(e_0 - e + \frac{0{,}5h-x}{2})] - \sum R'_{si}f'_{si}(e' - e) - R_b bx[(e_0 - e) + 0{,}5(h - x)] = 0 \quad (3.1.4\text{-}2)$$

where e_0 = eccentricity of the tension force from the geometric centre of gravity of the section;

e and e' = distance from the line of action of eccentrically applied force N to the centre of gravity of the tension and compression bar and sheet fittings, respectively. For other symbols, refer to 3.1.3.

3.1.5 In case of eccentric compression, the ultimate (breaking) force in the section of eccentric-compression members at $x \le \xi_R h_0$ and $\bar{a} > 0{,}25x$ shall be determined by the conditions:

$$N_u = R_b bx - 2(R_{sr} - R_b)(0{,}5h - x)\delta - \sum R_{si} f_{si} + R'_{si} f'_{si}; \quad (3.1.5\text{-}1)$$

$$Ne - (R_{sr} - R_b)[W_v + 2\delta(0{,}5h - x)(e_0 - e + \frac{0{,}5h - x}{2})] - \sum R'_{si} f'_{si}(e' - e) - R_b bx[(e_0 - e) + +0{,}5(h - x)] = 0. \quad (3.1.5\text{-}2)$$

For symbols in these dependencies, refer to 3.1.1 — 3.1.4.

3.2 Determination of ultimate (breaking) force in structures at inclined sections.

3.2.1 The ultimate (breaking) force at inclined section of an integrated structure shall be determined by the formula

$$Q_u = \sqrt{0{,}006 R_b b h_0^2 q_a}, \text{ kN}, \quad (3.2.1\text{-}1)$$

at $q_a = (H/h_0)\delta_c R_{sr} + R_{sx} f_x n / u_x$ (3.2.1-2)

where H = height of the rigid reinforcement profile;
h_0 = effective height of the section measured from the compression face of the section to the force resultant in bar fittings, sheet fittings and rigid reinforcement of the tension area;
δ_c = profile wall thickness;
R_{sr} and R_{sx} — design compressive strength of rigid reinforcement and cross rods (clamps), respectively;
f_x = area of cross rods (clamps);
n = number of legs of cross rods (clamps);
u_x = spacing of cross rods (clamps).

3.3 Calculation of crack resistance and determination of design crack width in reinforced concrete part of the structure.

3.3.1 Calculation of steel-concrete and integrated structures in terms of formation of the cracks normal to the member axis shall be made by the condition

$$M \le M_{cr} \quad (3.3.1\text{-}1)$$

where M = moment taken by the section normal to the longitudinal axis of the member during crack formation;

$$M_{cr} = R_t W_{red}. \quad (3.3.1\text{-}2)$$

W_{red} = elastic-plastic moment of compressive strength of the reduced section (expressed through the elastic moment of compressive strength of the reduced section and conversion factor k = 1,75 for the rectangular section and T-section).

3.3.2 The design crack width normal to the longitudinal axis of the integrated member at the level of the most tensioned bars of the flexible fittings shall be determined by the formula

$$a_{cr} = 40\frac{\sigma_s}{E_s}(3{,}5 - 100\mu)\sqrt[3]{d_{red}} \quad (3.3.2\text{-}1)$$

where μ = factor of reinforcement of the section equal to a ratio of all tension reinforcement to the area of concrete (taken not more than 0,02);
σ_s = stresses in the bars of the outermost row of the tension reinforcement;

$$\sigma_s = vMy/(\bar{v}J_{red}); \quad (3.3.2\text{-}2)$$

v = modular ratio;

$\bar{v}$ = concrete elastic ratio taken equal to 0,85 at the short-term and equal to 0,4 at the long-term load action;
J_{red} = inertia moment of the reduced section relative to its centre of gravity;
y = distance from the neutral axis of the reduced section to the outermost row of the tension bar fittings;

$$J_{red} = bx^3/6 + J_r v_r + F_{sr} v_r (h/2 - x)^2 + f_s v (h - a - x)^2 + f_s' v' (x - a')^2; \quad (3.3.2\text{-}3)$$

$$x = -F_{red}/b + \sqrt{(F_{red}/b)^2 + 2S_{red}/b}; \quad (3.3.2\text{-}4)$$

$$F_{red} = F_{sr} v_r + f_s v (h - a) + f_s' v'; \quad (3.3.2\text{-}5)$$

$$S_{red} = F_{sr} v_r \frac{h}{2} + f_s v (h - a) + f_s' v' a'; \quad (3.3.2\text{-}6)$$

h = depth of section;
d_{red} = reduced diameter of the rigid reinforcement and bar fittings located in the tension area, mm,

$$d_{red} = 4(f_{sr}^p + f_a)/L_s; \quad (3.3.2\text{-}7)$$

n_a = perimeter of the rigid reinforcement and bar fittings located in the tension area of the section.

APPENDIX 4

DETERMINATION OF THE CROSS SECTIONAL AREA OF ANCHORS

4.1 Cross sectional area of anchors T-welded to the flat members of steel embedded parts under bending moments M, normal N and shear Q forces shall be determined according to Fig. 4.1 and by Formula (4.1-1).

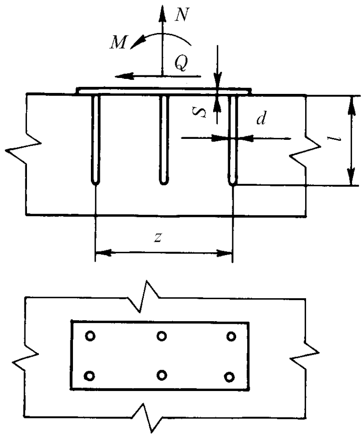

Fig. 4.1

$$F_{an} \geq 1{,}1\sqrt{N_r^2 + (Q_w/kk_1)^2}/R_s \qquad (4.1\text{-}1)$$

where F_{an} = total cross-sectional area of the anchors of the most stressed row, cm^2;
N_r = maximum tension force in one anchor row, N;

$$N_r = M/z + N/n_{an}; \qquad (4.1\text{-}2)$$

Q_{an} = shear force per anchor row;

$$Q_w = (Q - 0{,}3N_r')/n_{an}; \qquad (4.1\text{-}3)$$

N_p' = maximum compression force in one anchor row;

$$N_p' = M/z - N/n_{an}; \qquad (4.1\text{-}4)$$

M = bending moment determined in relation to the axis located in the plane of the outer face of the plate and passing through the centre of gravity of all anchors;
n_{an} = a number of anchor rows along the shear force direction; when the shear force Q is not uniformly transmitted to all rows of anchors, then not more than four rows shall be considered in determining the shear force Q_{an};
z = distance between outermost rows of anchors;

$$k_1 = 1/\sqrt{1+\omega} \geq 0{,}15; \qquad (4.1\text{-}5)$$

$\omega = 0{,}3N_r/Q_r$ at $N_p' > 0$,
$\omega = 0{,}6N/Q$ at $N_p' \leq 0$;

for anchor bars with a diameter of 8 — 25 mm

$$k = 4{,}75\sqrt[3]{R_b}/[(1 + 0{,}15f_b)\sqrt{R_s}] \leq 0{,}7; \qquad (4.1\text{-}6)$$

f_{an} = area of the anchor bar of the most stressed row.

The cross-sectional area of the anchors of the other rows shall be taken equal to the total cross sectional area of the anchors of the most stressed row.

Force N is considered positive when directed away from the embedded part. When forces N_r, N'_p and Q_w calculated by Formulas (4.1-2), (4.1-3) and (4.1-4) have a negative value, they shall be taken equal to zero in Formulas (4.1-1), (4.1-3) and (4.1-5). In addition, when the value of N_r is negative, in Formula (4.1-3) N shall be inserted instead of N'_p.

When the embedded part is located on the upper (during concreting) surface of the product, factor k shall be reduced by 20 %, and a value of N'_p shall be taken equal to zero.

4.2 The cross sectional area of anchors lap-welded to the plate under shear force shall be determined according to Fig. 4.2 and by Formula (4.2).

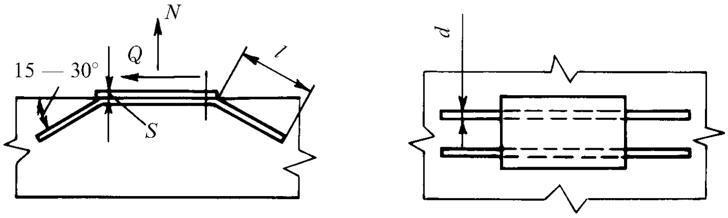

Fig. 4.2

$$F_{an} \geq 1{,}2Q/R_s. \tag{4.2}$$

The resistance of lap-welded anchors to shear force is taken into account for $Q > N$ (where N is the tension force) and for an anchor bend angle of 15–30°. In this case, T-welded anchors shall be installed with dimensions calculated according to Formula (4.1-1) where at k_1 = 1 and Q_r = 0,1 of the shear force determined by Formula (4.1-3).

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