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NON-METALLIC COMPOSITE REINFORCEMENT FOR CONSTRUCTION SITES

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Abstract. Non-metallic composite reinforcement (FRP) is distinguished depending on the type of reinforcing fibers. Allocate carbon fiber, fiberglass, basalt and organoplastic reinforcement.

The existing norms and recommendations for the calculation of structures made of NCA in most cases is a modification of the norms for the calculation of reinforced concrete structures made of steel reinforcement.

Common to all standards is the principle of design of structures using the method of limit states.

The article analyzes the existing domestic and foreign regulatory documents for the calculation and design of concrete structures with a satellite; the basic principles of the calculation of concrete structures with NSA and the design requirements for them have been determined; the stages of elaboration of standardization of requirements for various types of NSA and application for reinforcement of concrete structures have been established.

Introduction. Non-metallic composite reinforcement (FRP) is a composite material consisting of a synthetic polymer binder and reinforcing filamentary fibers. FRP are distinguished depending on the type of reinforcing fibers. Allocate carbon fiber, fiberglass, basalt and organoplastic reinforcement.

The main advantages of structures reinforced with NCA: durability and corrosion resistance; electromagnetic neutrality, dielectric properties; high strength and low specific weight of reinforcement; is subjected to instrumental processing; tool machined, simple workpiece on site. Effective areas of application of such fittings are: use in bank protection; marine and port facilities; sewerage, land reclamation and drainage; roadbed and fences, including bridges; elements of the infrastructure of chemical plants; products made of concrete with and without prestressing FRP; structures that do not lead to magnetic fields (transport structures, rooms for magnetic resonance imaging, radio-transparent structures); temporary structures and structures with slots, which are carried out on site.

Purposeful mass research, accompanied by the release of technical documents, only begun in the late 1970s.

The relevance of this work is due to insufficient study of the features of FRP collaboration with concrete and insufficient regulatory support and coverage of this problem in the technical literature.

Research Objective: get acquainted with the existing domestic and foreign regulatory documents for the calculation and design of concrete structures with FRP; to define the basic principles of calculation of concrete structures with FRP and design requirements for them; to establish the degree of elaboration of the standardization of requirements for various types of FRP and application for reinforcement of concrete structures.

1. Analysis of regulations for the calculation and design of concrete structures with FRP

1.1. General principles of calculation. Existing norms and recommendations for the design of FRP structures in most cases is a modification of the norms for the calculation of reinforced concrete structures made of steel reinforcement. Common to all standards is the principle of design of structures using the method of limit states. The first ULS (in terms of strength) and the second SLS (in terms of suitability for normal operation) limit state are selected. However, there are two approaches:

European – the design condition for limit states is written in the form R≥S, where R is the design resistance of the section, as a function of the design characteristics of materials (standard characteristic values divided by the safety factor for the material), S-forces in the section from external design influences and loads...

North American – the limiting state design condition is written in the form $\varphi \cdot R_n \geq S$, where R_n is the nominal section resistance, as a function of the normative (with a given security) characteristics of materials, φ is the generalized safety factor depending on the type of destruction, S-forces in the section from external design influences and loads. So, the main difference between the existing normative documents in the field of structural analysis from FRP is based on the principles of ensuring reliability. For European standards and recommendations, the reliability of calculations is ensured using separate safety factors for material and loads, and for American and Canadian standards – generalized safety factors (margin) for bearing capacity and safety factors for load. Japanese standards are characterized by the use of two principles at once: reliability is ensured by separate safety factors for material and additional safety factors for bearing capacity.

Foreign standards stipulate strength testing, taking into account duration and high-cycle loads, by the method of permissible stresses as part of calculations for the second limit state SLS. The permissible stresses are determined taking into account the material safety factor for the second limiting state (γ = 1.0) and the corresponding operating conditions factor.

1.2. Standardization of material characteristics. The calculated value of the strength (deformation) characteristics is determined in general form by the formula:

$$R = \eta \cdot R_n / \gamma_R \tag{1}$$

where R_n – is the standard (with a security of 0.95) value of strength or deformation; γR – material safety factor; η is the product of the coefficients of working conditions (taking into account the duration, the cycle of loads, external conditions).

For FRP, the material safety factor is set only in European standards. In the Italian CNR-DT 203, the value of the coefficient γ = 1.5 for calculations for the first limiting state and 1.0 for the second. In the bulletin FIB and ModelCode 2010 it is proposed for the first limiting state to take values of the safety factor γ not less than 1.25. In the ACI standards, the γR coefficient as such is absent, however, the standard (guaranteed by the manufacturer) value is determined with a security of 0.9986, while the generalized safety factor (margin) φ=0.5-0.7 is additionally pointed.

To take into account the external conditions affecting the strength and deformation properties of FRP, the provided coefficient of working conditions (in different regulatory documents has a different designation). Table 1.1 summary data on the values of the coefficients of working conditions according to the regulatory documents of various countries.

In the recommendations of NIIZhB 1978 for fiberglass reinforcement, the following operating conditions were introduced, taking into account the possibility of incomplete use of the strength properties of FRP due to prolonged stress action, uneven stress distribution in the section, anchorage conditions, and operating conditions: m_{ad} = 0,65 – is a coefficient taking into account the long-term action of the load, which is applied for all design combinations of loads; m_{at} = 0,9 – coefficient taking into account the effect of elevated temperature (short-term heating to 100° C during production, prolonged exposure to 80 ° C, steaming at 60° C); m_{ak} = 0,7-0.8 – coefficient taking into account the influence of an aggressive environment on the structure during the operation of aggressive environments.

The material reliability factor is standardized in the recommendations of NIIZHB-1.3.

Table 1.1. Service Factors for FRP

Factor taken into account	ACI 440.1R-06	NS3473 (Norway)	CSA-S6-00 (Canada)	JSCE (Japan)	IstructE (UK)	CNR-DT 203 (Italy)
External conditions (first and second limit state)	Dry: СП – 0,8 ОП – 0,9 ВП – 1,0 Wet: СП – 0,7 ОП – 0,8 ВП – 0,9	СП – 0,5 ОП – 0,9 ВП – 1,0	СП – 0,5 ОП – 0,6 ВП – 0,75	СП – 0,77 ОП – 0,87 ВП – 0,87		Dry: СП – 0,8 ОП – 0,9 ВП – 1,0 Wet: СП – 0,7 ОП – 0,8 ВП – 0,9
Duration and cycle of loads	СП – 0,2 ОП – 0,3 ВП – 0,55	СП–0,8-1,0 ОП–0,7-1,0 ВП–0,9-1,0	СП–0,3-0,4 ОП–0,3-0,6 ВП–0,7-0,9		СП – 0,27 ОП – 0,45 ВП – 0,55	СП – 0,3 ОП – 0,5 ВП – 0,9
Legend: SP - fiberglass, OP - organic plastic, OP - carbon fiber						

In the draft Ukrainian DSTU standards for basalt and fiberglass reinforcement (FRP, which is manufactured according to technical specifications), specific values of the safety factor are not presented. Additional service factors for FRP are NOT standardized. In the draft DSTU standards, a design ratio for determining the compressive strength of FRP is established:

$$f_{fdc} = 0,2 f_{fd} \quad (2)$$

where f_{fdc} – is the design compressive strength of FRP, ffd is the design tensile strength of FRP.

1.3. Calculation for the first group of limit states. Calculations for the first group of limiting (ULS) states (in terms of strength) are performed with the design characteristics of materials and design forces. The principles of calculation of bending elements in all the codes are the same as those adopted for the calculation of structures made of steel reinforcement. Basically, the calculation by the method of limiting efforts is presented. The main hypotheses underlying the calculation of bending elements for the considered norms and recommendations – the hypothesis of flat sections is performed at all stages of the section operation; availability of joint work of FRP and concrete; tensile work of concrete is not taken into account; FRP compression work is not considered; FRP works on a linear elastic diagram to fracture; the regularities of concrete deformation are preserved, as for the calculations of structures made of steel reinforcement.

The principles of the calculation of the shear force in the norms are the same as those adopted for the calculation of structures made of steel reinforcement. At the same time, the features associated with the physical and mechanical characteristics of FRP and the peculiarities of its operation in conjunction with concrete (anisotropy of the material, significant deflections and crack opening width, lower height of the FRP, etc.). The difference between the methods lies in the difference between the main empirical and theoretical models for calculating the shear force adopted in various national standards.

1.4. Calculation for the second group of limit states. Calculations for the second group of limiting states are performed with a combination of standard loads. Calculations for the second group of limiting states include calculations for deformations and calculations for the formation and opening of cracks.

The calculation for the second group of limiting states in foreign standards additionally includes checking the strength taking into account the duration and high-cycle loads according to the method of permissible stresses (checking with long-term standard loads).

This check is also provided for reinforced concrete structures by ACI 318 and Eurocode 2. The requirements are based on the inadmissibility of the operation of sections under long-term standard loads in the inelastic stage (see Section 7.2. EN 1992-1-1). According to ACI standards, conditions are similar, but the coefficients of working conditions are more careful η = 0.2-0.55 depending on the type of material.

The value of the limiting deflection value is standardized depending on the span of the structure. In Russian standards, the limiting values of deflections are currently set in SP 20. In the considered foreign regulatory documents for FRP structures, the same restrictions are adopted that are established for reinforced concrete structures in the corresponding documents. Similar requirements are established in the draft Ukrainian DSTU standards. The European recommendations fib proposed a design model related to the methodology for calculating reinforced concrete structures according to Eurocode 1.

The methods for calculating the crack opening width are also based on the constraints developed for reinforced concrete structures. At the same time, the crack opening width, as a rule, is determined by the functional dependences on the stresses in the reinforcement, the concrete cover and the crack spacing. The analysis of the calculation for the second group of limit states of the norms and recommendations of various countries is presented in Table 1.3.

Table 1.2. Minimum quantity (percentage of reinforcement ρ) of transverse reinforcement according to different standards and recommendations

Standards for r.c. structures	ρ_w	Norms for FRP	ρ_{fw}
ACI 318-08 (USA)	$0,06\sqrt{f_c^{/}}\frac{1}{f_y} > 0,35\frac{1}{f_y}$	ACI 440.1R-06	$0,35\frac{1}{f_{fw}}$
CSA A 23.3-94(Canada)	$0,06\sqrt{f_c^{/}}\frac{1}{f_y}$	CAN/CSA- S806-02	$0,3\sqrt{f_c^{/}}\frac{1}{f_{fw}}$
BS 8110 (UK)	$0,4\frac{1}{f_y}$	IstuctE-99	$0,4\frac{1}{0,0025 \bullet E_f}$
EN 1992-1-1 (European Union)	$0,08\sqrt{f_c^{/}}\frac{1}{f_y}$	Research	$0,08\sqrt{f_c^{/}}\frac{1}{0,0045 \bullet E_y}$
		CNR (Italy)	$A_{fw,\min} = 0,06\sqrt{f_{ck}}\frac{b \bullet s}{0,004 \bullet E_f}$ but not less $\frac{0,35 b \bullet s}{0,004 \bullet E_f}$

f_w – design strength of transverse reinforcement, no more tha $0,004E_f$, f_y yield strength of steel reinforcement.

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		CNR (Italy)	$A_{fw,\min} = 0,06\sqrt{f_{ck}}\frac{b \bullet s}{0,004 \bullet E_f}$ $\frac{0,35 b \bullet s}{0,004 \bullet E_f}$

fw – design strength of transverse reinforcement, no more than $0,004E_f$, f_y - yield strength of steel reinforcement.

Table 1.3. Limit values of crack opening width

Norms	Fittings	Terms of use	Acrc,ult
Сп 52-101-2003	Hot rolled steel	Normal	0,3-0,4мм
Eurocode 2	Steel	Normal	0.4мм
Eurocode 2	Steel	Aggressive environment	0,3мм
Aci 318	Steel	Normal (indoor)	0.4мм
Aci 318	Steel	High humidity (operation outdoors or in soil)	0,3мм
Jsce	Frp	-	0,5мм
Aci 440 Csa	Frp	Normal (indoor)	0,7мм
Aci 440 Csa	Frp	High humidity (operation outdoors or in soil)	0,5мм
Cnr	Frp	-	0,5мм With continued effort
DSTU project	FRP (fiberglass, basalt)	Structures open for inspection (aesthetic and psychological requirements)	0,4мм
DSTU project	FRP (fiberglass, basalt)	Hidden surfaces of structures	0,8мм
Recommendations NIIZHB 1978	Fiberglassa	-	Cracks without special justification are not allowed

2. Experimental theoretical studies of the properties of frp and concrete structures reinforced with it

This section presents a list of previous studies of FRP properties and actual performance of FRP-reinforced structures, and the main results obtained in these studies. All results are presented in tabular form (Table 1.4., 1.5, 1.6).

Regular international conferences held since 1993 on the results of experimental and theoretical studies of the properties of FRP and FRP-reinforced structures. The published results, for the most part, are the basis for the development of international norms and recommendations and are taken into account when developing the calculated dependencies and coefficients of working conditions. Each collection presents relevant research on the topics: physical and mechanical properties of FRP, durability, long-term properties, studies of the actual operation of structures under various force effects, prestressed structures, adhesion and anchoring, reinforcement, etc.

Table 1.4. Limit value of prestressing according to standards

FRP type	FRP pretensioning limit		Tension in FRP after tension release	
	Reinforcement with adhesion to concrete	Tension on concrete	Reinforcement with adhesion to concrete	Tension on concrete
Carbon fiber	$0,7f_{pu}$	$0,7f_{pu}$	А) $0,65f_{pu}$ Б) $0,60f_{pu}$	$0,65f_{pu}$
Organoplastic	$0,4f_{pu}$	$0,4f_{pu}$	А) $0,35f_{pu}$ Б) $0,38f_{pu}$	$0,35f_{pu}$
Fiberglass	А) $0,30f_{pu}$ Б) -	А) $0,30f_{pu}$ Б) -	А) $0,25f_{pu}$ Б) -	А) $0,25f_{pu}$ Б) -
a) norms for the calculation of bridges; b) norms for calculating buildings and structures; f_{pu} – FRP tensile strength				

Table 1.5. Minimum percentage of non-stress reinforcement

Design	FRP type	Stress in the tensile zone of the concrete section			
		$\leq 0,5\sqrt{f_c}$		$>0,5\sqrt{f_c}$	
		Reinforcement with adhesion to concrete	Tension on concrete	Reinforcement with adhesion to concrete	Tension on concrete
Beam	Carbon fiber	0	$0,0044A_b$	$0,0036A_b$	$0,0055A_b$
	Organoplastic	0	$0,0048A_b$	$0,0036A_b$	$0,0050A_b$
Plate	Carbon fiber	0	$0,0033A_b$	$0,0022A_b$	$0,0044A_b$
	Organoplastic	0	$0,0036A_b$	$0,0024A_b$	$0,0048A_b$

$A_b=b\cdot h$ – concrete section area of an element.

Table 1.6. Minimum length of tension transfer and anchorage zone

FRP type	Diameter d, mm	Length of tension transfer zone	Length of the survey zone
CFRP-Rod FRP	-	60d	180d
CFRP - rope	-	20d	50d
Organoplastic	(8-12)	50d	120d
Organoplastic	(12-16)	40d	100d
Organoplastic	≥16	35d	80d

Conclusions:

1. The main regulatory documents and recommendations for the design of FRP structures have been developed in the USA, Canada, Japan, Great Britain, Italy in recent years on the basis of the norms for the calculation of reinforced concrete structures made of steel reinforcement. Drafts of normative documents have been prepared in Ukraine and Russia.

2. The basic principles of calculation of elements with FRP are preserved as for reinforced concrete structures, taking into account the linear operation of FRP. The specificity of the work of FRP structures is taken into account by the introduction of special reducing factors for working conditions and the standardization of the characteristics of materials.

3. The issues of standardization of requirements for glass, organo and carbon fiber reinforcement have been worked out to a greater extent. The use of basalt-plastic reinforcement as prestressing FRP requires additional non-standardization.

4. The STO project developed in NOSTRO presents general design solutions and technological conditions, which mainly relate to geotechnical structures. There are no methods for calculating FRP structures and standardizing the design characteristics of such reinforcement in this document. In the Guidelines on the design and manufacture of concrete structures with FRP, recommendations are given for standardizing the characteristics of composite reinforcement based on basalt and glass roving.

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EVALUATION OF THE EFFICIENCY OF PROTECTION AGAINST IMPACT NOISE OF EXPERIMENTAL FLOOR STRUCTURES

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Abstract. This article is devoted to an important problem of modern construction of multi-storey frame-monolithic residential buildings, namely the solution of the problem of sound insulation of premises from shock