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USE OF WET CONCRETE SPRAYING IN BUILDING TECHNOLOGY OF REINFORCED-CONCRETE FIBER SLABS ACCORDING TO «MONOFANT» SYSTEM

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Abstract. *Technology of cementation of reinforced-concrete slabs with non-extractable-liners for the «Monofant» system, using wet concrete spraying is implemented. A compression test for obtained columns made of fiber concrete is carried out.*

Key words: *system «Monofant» system, column, non-extractable-liners, fiber concrete, fiber, wet concrete spraying.*

ПРИМЕНЕНИЕ МОКРОГО ТОРКРЕТИРОВАНИЯ ДЛЯ ВОЗВЕДЕНИЯ ИЗ ФИБРОБЕТОНА ЖЕЛЕЗОБЕТОННЫХ КОЛОНН ПО СИСТЕМЕ «МОНОФАНТ»

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Аннотация. *Реализована технология бетонирования железобетонных колонн с неизвлекаемыми вкладышами-пустотообразователями для системы «Монофант» с помощью мокрого торкретирования. Проведено испытание на сжатие полученных колонн из торкрет-фибробетона.*

Ключевые слова: *система «Монофант», колонна, неизвлекаемый вкладыш-пустотообразователь, фибробетон, фибра, мокрое торкретирование.*

ЗАСТОСУВАННЯ МОКРОГО ТОРКРЕТУВАННЯ ДЛЯ ЗВЕДЕННЯ З ФІБРОБЕТОНУ ЗАЛІЗОБЕТОННИХ КОЛОН ЗА СИСТЕМОЮ «МОНОФАНТ»

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Анотація. *Реалізовано технологію бетонування залізобетонних колон з вкладишами-пустотоутворювачами, які не виймаються, для системи «Монофант» за допомогою мокрого торкретування. Проведено випробування на стиск отриманих колон з торкрет-фібробетону.*

Ключові слова: *система «Монофант», колона, вкладиш-пустотоутворювач, який не виймається, фібробетон, фібра, мокре торкретування.*

Introduction

In Ukraine, construction of buildings and structures with the use of lightweight frame systems has become widely used [1–3].

The feature of the «Monofant» system used for construction of monolithic reinforced concrete frames consists in using two different technologies: for elements of buildings and structures of horizontal and vertical form - application of self-compacting concrete, and for the elements of curved shape it is the use of wet spraying [3].

The process of further development of the technology of lightweight reinforced concrete structures concreting, using liners to dump in order to reduce the weight, not only of concrete floors, but of all major elements of the framed building, requires extensive research of both the wet spraying process, and the strength characteristics obtained in the course of structures concreting.

Content Analysis

The world construction practice has revealed that fibrous concrete is one of the most promising building materials of the XXI century. In recent years, the use of fiber concrete reinforced with synthetic fibers in monolithic structures of buildings and constructions has greatly increased [4–6].

However, the technical characteristics of different grains for manufacturing fibers differ significantly (table. 1). From the presented list the most effective for disperse reinforcement of concrete in order to significantly increase its strength can be considered to be glass, basalt, steel and carbon fibers. Studies in question suggest that dispersed reinforcing by both steel and synthetic fibers greatly enhances the early strength of the concrete as well as increases the kinetics of strength growth to 28 days (table. 2, 3).

Table 1 Technical characteristics of fibers [6]

Fiber	Density, g/cc	Tensile breaking strenth, HPa	Modulus of elastisity, HPa	Breaking elongation, %	Dimensional characteristics (length×diameter), mm
polypropylene	0,9	0,40-0,77	3,5-8	10-25	5-30×0,005-0,015
polyethylene	0,95	0,70	1,4-4,2	10	5-30×0,005-0,015
nylon	1,1	0,77-0,84	4,2	16-20	5-30×0,005-0,02
acrylic	1,1	0,21-0,42	2Д	25-45	5-30×0,005-0,02
polyether	1,4	0,73-0,78	8,4	11-13	5-30×0,005-0,02
cottonous	1,5	0,42-0,70	4,9	3-10	0,1-10×0,001-0,05
asbestic	2,6	0,91-3,10	68	0,6	0,1-10×0,001-0,05
glass	2,6	1,05-3,25	70-80	1,5-3,5	5-50×0,005-0,05
basaltic	2,65	1,90-3,90	90-130	1,2-3,2	5-50×0,005-0,05
steel	7,8	0,8-3,10	200	3,5-4,0	5-50×0,1-2,0
carbonic	2,0	2,00	245	1,0	5-30×0,005-0,05

Table 2 Effect of the reinforcing fibers on the strength of fiber concrete during the first hours of hardening [4]

№ p/p	Time, h	Tensile breaking strength under bending, $\times10^{-2}$ MPa				
		Concrete without fibers	Concrete reinforced by nylon fibers in the volume of, %		Concrete reinforced by steel fibers in the volume of, %	
			1,5	3,0	1,5	3,0
1	0	0,6	0,8	1,0	1,0	1,3
2	1	0,7	1,4	1,5	1,3	1,8
3	2	1,1	2,3	2,2	2,0	2,6
4	3	1,7	3,0	2,8	2,6	3,4

Table 3 Kinetics of concrete strength increase over time [4]

Type of concrete	Volume percent of reinforcement	Strength	Failure limit (MPa), days			
			1	3	7	28
Concrete without fibers	0	bending tension	2,7	5,7	6,0	6,7
		under compression	8,6	24,1	28,4	39,6
Concrete reinforced by capronic fiber	1,5	bending tension	4,2	6,1	7,4	7,5
		under compression	9,7	26,8	29,1	44,6
Concrete reinforced by steel fiber	1,5	bending tension	7,6	9,7	12,3	15,4
		under compression	10,1	29,3	35,6	50,1

Similar patterns were obtained when testing concrete samples with polyacrylic [7] and basalt fibers [5, 8].

In addressing the issues of disperse reinforcement of concrete materials one should take into account that not all synthetic fibers can withstand the environment of cement hydration. Glass fibers of common composition are subjected to intensive corrosion in the hardening concrete based on Portland cement [6]. From a number of mineral fibers, by assessing their stability in alkaline media, polyamide fibers differentiate (tab. 4).

Table 4 Properties of nonmetallic fibers in relation to alkali [4]

Types of fibers	Relation to alkali
Mineral:	
asbestos	resistant
glass (aluminoborosilicate)	insufficiently resistant
glass (zirconium)	resistant
quartz	resistant
carbon	resistant
basalt	comparatively resistant
boron	resistant
Chemical:	
viscose	not resistant
alkali	not resistant
cellulose	resistant
Synthetic:	
polypropylene	resistant
polyether	insufficiently resistant
polyvinylchloride	resistant
polyvinylalcohol	extremely resistant
polyamide (nylon, capron)	extremely resistant

Coupling of fibers with a cement matrix is a very important characteristic (tab. 5).

Unlike steel fibers, metallic fibers cannot create in the mixture a rigid three-dimensional structure; however, being located in the intergranular space of the filler and due to its ultrahigh dispersion, even at low saturation of mixtures they also form a space frame therein. Moreover, if the high modulus fibers are hardeners for dense concrete, then the low modulus fibers, through the modification of the cement matrix structure, do much in support to enhance the durability characteristics of fiber-reinforced concrete. In this case, the length of the fibers is not so critical, and the introduction of even very short fibers leads to the achievement of the desired result [4].

Table 5 Adhesion characteristics of fibers with a cement matrix made of normal density slurry mix [4]

Type of fiber	Adhesion index (MPa) using the brand of cement	
	M 400 D20	M 400 D20
Steel and wavy made of wire of low carbon content	1,52	2,51
Steel and wavy made of low steel content	2,16	3,45
Basalt	1,45	2,06
Cellulose	0,1	0,31
Capron	0,5	1,3

When it is necessary to increase the strength of concrete the relative length of both high modulus and low modulus fibers should be limited to a threshold size, as this may lead to fiber clumping and reducing the technological and functional properties of the concrete mix.

The relation between the geometric parameters of the used components of the sprayed fiber-reinforced concrete mix and the length of non-metal fibers is determined by methodological recommendations [9].

All these factors affecting the properties of the fiber-reinforced concrete should be taken into account when concreting lightweight structures, using the method of wet spraying.

The purpose and task setting

The aim of the work is to develop a technology for manufacturing lightweight construction elements made of concrete and fiber-concrete mixtures by the method of wet spraying.

Basically, the task of the study was comparing the strength characteristics of columns fragments made of sprayed reinforced concrete and sprayed fiber-reinforced concrete.

Working out of the manufacturing technique of structures by wet spraying and tests of concreted columns fragments

To develop the technology of wet spraying and select the composition of the sprayed concrete mix, there was carried out concreting of slab fragments and the column of square and circular cross-section (fig. 1).

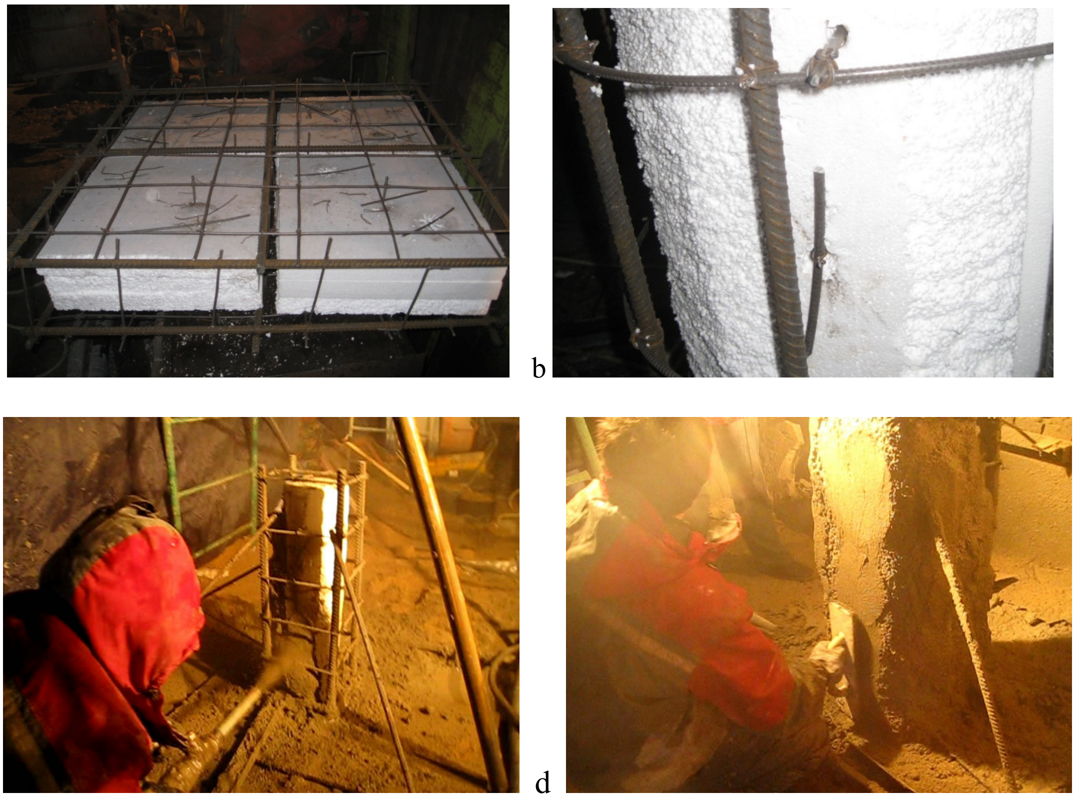

Fig. 1. Production of fragments of reinforced concrete structures: a – a metal frame with a non-removable liner; b – fixing of the liner made of polystyrene; c – spraying of the square pillar fragment; d) surface smoothing after wet spraying

As a fiber, there was chosen the PAN fiber, which is a high modulus polyacrylonitrile synthetic fiber, specially designed for use in concrete, mortar and applicable to various types of cement (fig. 2). The main difference between PAN-fibers from other synthetic fibers is a high adhesion to the mineral matrix as a result of the combined action of the surface layer and the CN-group of the polymer fiber chain with the OH-group of hydrosilicates, hydroaluminates or other components of the mixture (tab. 6).

Fig. 2. PAN-fiber

Table 6 PAN-fiber technical characteristics

Fiber Type	PAN
linear density, tex	0,17, 0,33, 0,56 0,68, 0,77
Tensile strength, MPa	before 500
Tensile modulus, GPa	no more 11
Density, g/ cc	1,17
Fiber break elongation	26 %
Cutting length, mm	6, 12, 18, 24
Humidity	1,0-4,0 %

The composition of the sprayed fiber-reinforced concrete was selected in accordance with the technical specifications [10]: cement M300 – 750 kg, sand – 1500 kg, water – 200 liters, superplasticizer C-3 – 10 liters, mineral additive – 30 kg of mineral powder, PAN fiber – 5 kg.

PAN-fiber meets the following requirements [11]: the length of 6 mm, the linear density 0,33 tex at a rate of 0,3 % of the sprayed concrete. Tex is the main term used to describe the linear density of fibers in the composite materials industry. It is defined as the weight in grams of 1000 meters of fiber. Preliminary, according to drawings there were connected the reinforcement cages of the column fragments. Inside the frame by means of clamps, to create a protective layer of 30 mm thickness, there was fixed a liner made of polystyrene. To prevent displacement of carcasses, in the process of concrete mix spraying they were fixed between each other by reinforcement bars. Upon the completion of works the rods were removed, and the resulting voids in the contact areas of both the reinforcement and the carcass were rubbed by a clean solution. Preparation of the concrete mixture was produced in a mobile cyclical compulsory mortar mixer type RN-200. After the preparation the mixture was fed into a screw-type mortar pump S5 Putzmeister. To spray the concrete mixture on the frame of columns fragments, a mobile mortar compressor Kaeser Mobilair M43 was connected to the mortar pump. While gunning the consumption of both the concrete and fiber-reinforced concrete mixture was 0,1 cm/minute, the pressure in the system was 5–6 atm. After the process of cement spraying is over, using hand tools there was removed excess cement mixture and the alignment of columns fragments was performed. Simultaneously, while gunning the mixture there were produced specimens in the form of cubes, using both compositions to control the strength of the concrete during the project age. All samples were placed on storage at 20±5 ^{0}C and 40-60% humidity during 28 days to accumulate the design strength. After the design strength was accumulated by the concrete of columns fragments, there were conducted their strength tests on the basis of the Test Center of Technical Means of the Rail Transport of Moscow State University of Railway Transport under the guidance of professor V. Kondrashchenko. The column fragment took the form of a hollow column having an outside diameter of 400 mm, with an internal diameter of 280 mm and 1000 mm height. The thickness of the concrete in the upper and lower part was 100 mm. There were produced four samples (two samples were made of sprayed reinforced concrete and the other two of sprayed fiber-reinforced concrete). The main reinforcement of the column was formed of 8 class A500 rods with a diameter of 12 mm. To form an unrecoverable liner, they used Polystyrene (fig. 3).


a d c d

Fig. 3. Column fragment test: a – a framework for producing the column; b – ready columns before the test; c – alignment of sensors to determine the strain; d – a ruined column fragment

The design was performed by the finite element analysis of a reinforced concrete hollow cylindrical column, using the «ANSYS» program to determine the breaking load and compare it with the experimental one.

For the calculation of reinforced concrete columns used B40 class concrete with the following characteristics:
– modulus of elasticity 36000 MPa;
– compressive strength 55 MPa;
– coefficient of transverse deformation 0,2.

To take into account the physical non-linearity of both the concrete and steel of the reinforcement there was build the diagram «σ–ε» in accordance with the requirements of SP 52-101-2003 «Concrete and Reinforced Concrete Structures without Preliminary Strain» (fig. 4, 5).

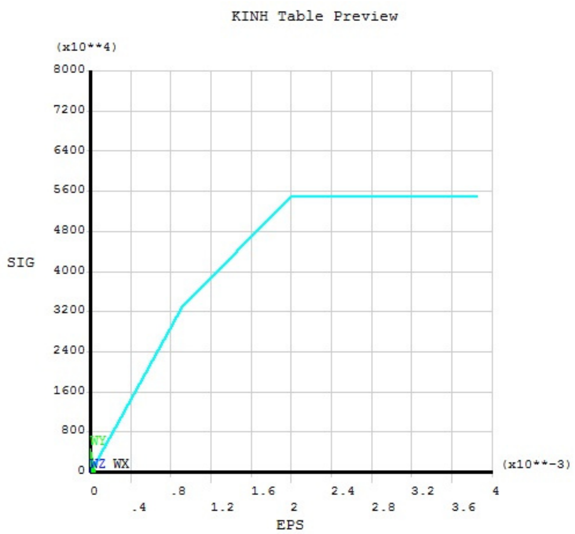

Fig. 4. Diagram «σ-ε» for concrete

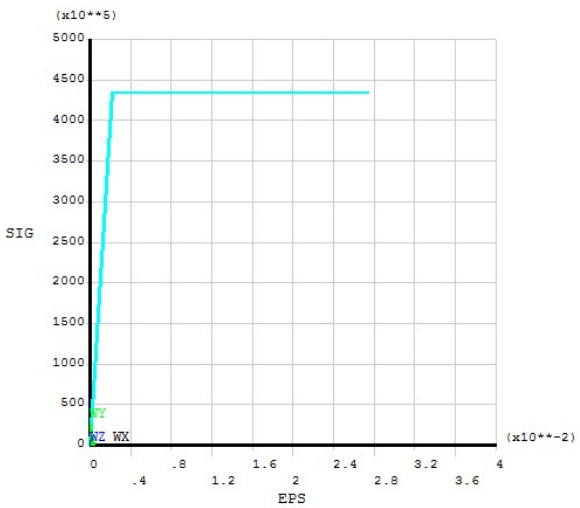

Fig. 5. Diagram «σ-ε» for reinforcement steel

For reinforcement they applied armature class A500 with the following characteristics:
– modulus of elasticity 200,000 MPa;
– tensile strength 435 MPa;
– coefficient of transverse deformation 0,3.

To simulate the loading plate, the material with the following characteristics is used:
– modulus of elasticity 200000×10^{9} MPa;
– coefficient of transverse deformation 0,1.

The material in question was designed to simulate the «absolutely» rigid material.

To solve this problem, the design scheme of the column consisted of a quarter, taking into account the symmetry of the structure. The concrete column body was set by the volume finite element (as well as for the loading plate), and for reinforcement modeling they used a one-dimensional rod. Subsequently, the concrete body element nodes and the nodes of reinforcing bars were concatenated into one to provide interaction.

The boundary conditions corresponded to the cantilevered restraint: the side faces are free of stress, on the lower edge there were no linear and angular movements. The load was set as a distributed one and applied to the upper surface of the loading plate.

After the experimental determination of the load for control columns (about 100 ton force), in the given problem there was accepted the equivalent distributed load of 6, 6×106 Pa, which at translation (the radius of the charging unit is 0,22 m) into the concentrated force equals about 1000 kN (fig. 6).

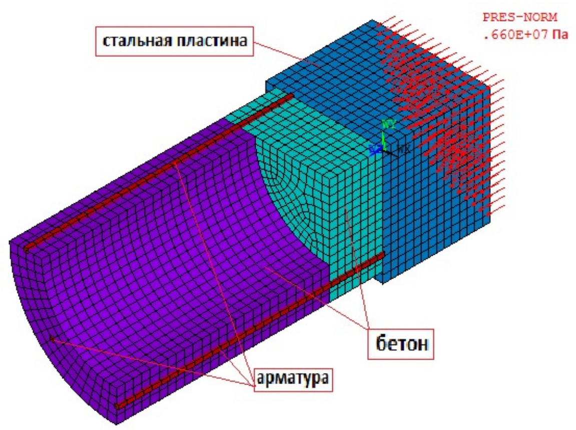

Fig. 6. Designed finite element scheme of the column

The calculation was performed taking into account the physical nonlinearity of materials. After the design had been performed, analysis of the following indicators was carried out:

– distribution of volume deformations (fig. 7).
– the value of the principal tensile stress (fig. 8);
– assessment of the limit state according to Mises criteria (fig. 9).
– distribution of the vertical deformation (fig. 10);
– evaluation of linear horizontal displacements (fig. 11).

Analysis of the calculation results and their comparison with the experimental data showed sufficient adequacy of the proposed model (tab. 7).

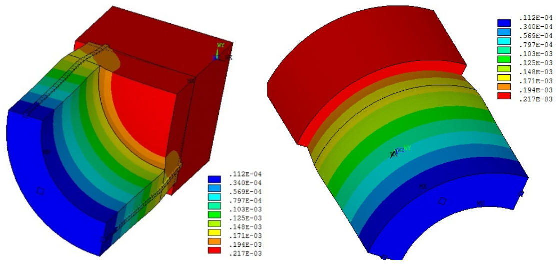

Fig. 7. Bulk deformation

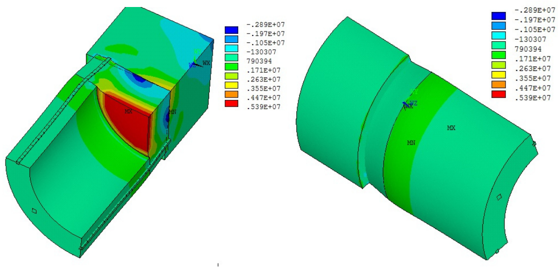

Fig. 8. Main tensile stresses

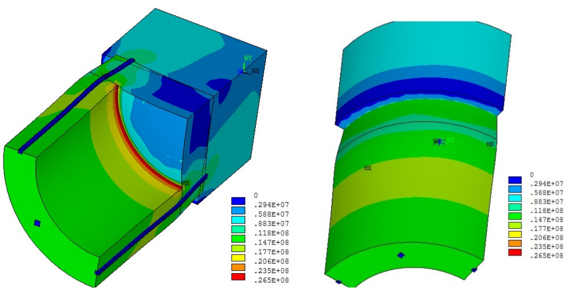

Fig. 9. Assessment of the limit state according to the Mises criteria

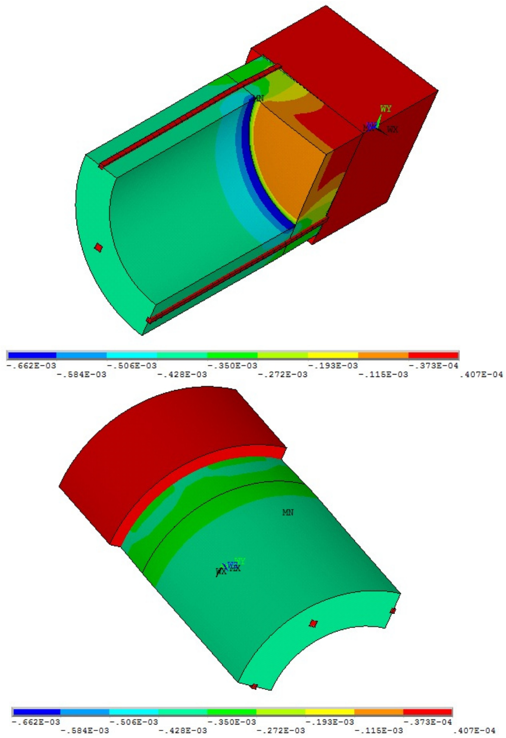

Fig. 10. Vertical deformation

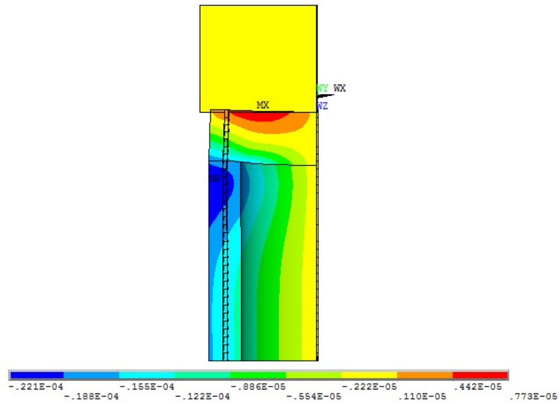

Fig. 11. Linear horizontal movement

Table 7 Summary of test results

Parameter	Test results	
	Experiment	ANSYS
Breaking strength, кН	1000*	1000
Vertical deformation, mm	0,0005	0,0004
Horizontal movement, mm	0,04**	0,02

* to compare the results there was accepted the load of 1000 kN for columns made of fiber-reinforced concrete;
** the given result was obtained for the barrel-shaped deformation of the column: (0,26-0,18)/2 = 0,04 mm.

There was also revealed a matching of the column fracture zone at both full-scale and numerical experiments, while a more intensive destruction of concrete (cracking) was observed in the lower zone of the concrete «cap» of the column. In fig. 3 d there is a visible destruction of concrete in the area matching the experimental one (the main tensile stresses in this area constitute about 2 MPa, which is typical of class B40 concrete).

Conclusions

The technology of wet concrete spraying method, which allows concreting the vertical elements of buildings and structures avoiding vibration and use the minimum amount of inventory formwork, is developed. The use of nonmetallic fibers in the composition of the sprayed concrete mix did not result into an increase of the bearing capacity of reinforced concrete columns, but reduced the rebound of the concrete mix up to 5–7 %.

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