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DETERMINATION AND USE OF HIDDEN STRENGTH RESERVES OF CENTRIFUGED REINFORCED CONSTRUCTIONS BY MEANS OF CALCULATION AND EXPERIMENTAL METHODS

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Statement of the problem. When centrifuging elements with a sufficiently thick wall, the effect of centrifugal and centripetal forces acting on different internal layers of the cross section varies greatly, which leads to a significant difference in the structure, physical, mechanical and structural characteristics of concrete layers, which in some cases must be taken into account in the calculations. It becomes possible to use substantial reserves of structural strength that can be determined by means of calculation and experimental methods. The paper posed and solved the problem of identifying the difference in pro-perties and characteristics of layers of centrifuged reinforced concrete structures, its analytical description, adjusting the strength calculation methods to account for this and comparing them with the existing regulatory methods for calculating strength in the current regulations.

Results and conclusions. A model of a three-layer variotropic structure of a centrifuged structure is proposed, its substantiation, expediency and efficiency are experimentally confirmed. When comparing the methods of calculating standard centrifuged reinforced concrete columns, it was concluded that the values of their strength calculated based on the integral (generalized) and differential (layered) characteristics differ significantly. The previously hidden latent reserves of industrial columns of the variotropic structure produced by centrifuging methods are not analytically identified.

Keywords: centrifuged reinforced concrete structures, variotropic properties of sections, layers of concrete, calculation of the strength of building structures, integral and differential characteristics of centrifuged concrete.

Introduction. The centrifugation method for the production of circular elements has proven highly efficient in a variety of structures. Extensive experience has been gained in the manufacture of centrifuged reinforced concrete elements of the circular section, i.e., pipes, electricity transmission supports, lighting masts and contact network supports, columns of one- and multi-storey buildings, etc.

The analysis shows that the method of centrifugation in the molding of products from high-strength concrete is easy to employ, does not require sophisticated equipment and is highly efficient. At its current stage of development, the centrifugation technology is being continuously improved.

The use of the centrifugation methods such as layer-by-layer molding, centrifugal rolling, cyclic centrifugation, combining centrifugation of a concrete mix by means of vibration and rolling, reverse centrifugation, modification of centrifuged concrete with complex chemical additives and the like, allows us to tackle the production of high-strength concrete for heavily loaded columns [1, 9—11, 13].

1. The theoretical basis for the formation of centrifuged concrete structure. When centrifuging elements with a sufficiently thick wall, centrifugal and centripetal forces acting on different (external and internal) layers of the cross section are significantly different, which leads to a considerable difference in the structure and physical and mechanical as well as structural characteristics of the layers of the element, which in some cases must be accounted for in calculations [2—4, 14, 15].

Manufacturing elements by centrifugation [11] involves the mold with a concrete mix rotating around a fixed axis, a compressive centrifugal pressure occurs resulting in a liquid being squeezed from a cement gel with highly dispersed fractions suspended in it and larger particles of the solid phase coming together. Such a concrete during single-layer molding without plasticizing additives differs from concrete manufactured by means of vibration compaction as it has the property of inhomogeneous distribution of aggregate grains over the product wall thickness, since larger grains are squeezed to the outer surface by the inertia forces and smaller grains to the inner one.

Therefore the disadvantages of centrifuged concrete during single-layer molding commonly include its cross-section anisotropy and change in strength characteristics along the thickness of a wall [16, 17]. However, some questions arise: first of all, whether this is a drawback at all and, second of all, how this phenomenon can possibly be taken advantage of for calculating and designing centrifuged structures. In the process of manufacturing samples on a belt centrifuge during single-layer molding, I. N. Akhverdov [1] identified the following structural anisotropy of concrete:

— on the outer surface, the most dense water is squeezed out and the cement paste is densified;

— in the middle part of the section, a significant heterogeneity of the cement stone is caused by radial filtration channels in it, their dimensions of the section and the number increase from the outer to the inner surface of a product;

— as they approach the inner surface of the product, the microcapillaries are connected and form macrocapillaries, which then form a system of dispersed ducts that disappear due to dilution of a cement gel with water displaced from the upper zones.

All of these lead to the fact that the structure and strength of the same centrifuged concrete varies in thickness. As a result, there is what is now referred to as variatropia.

The data obtained by V. P. Petrov [12] showed that after being centrifuged for 20 minutes, the strength difference between the outer I and middle II concrete layers is 7.6 % and between the outer I and inner III concrete layers it is 20.1 %.

Moreover, the strength of centrifuged concrete of layers I and II was higher than that of similar vibrated concrete, and was lower in layer III. At the same time, the porosity in all of the zones of centrifuged concrete was lower than that of vibrated concrete. The experimental results [12] are presented in Table 1 and 2.

Table 1

Results of the tests of centrifuged concrete

Layer	Compressive strength limit, MPa	Variation coefficient, %	Water absorption according to the GOST (ГОСТ) 12730.3-78, %	Porosity according to the GOST (ГОСТ) 12730.4-78, %
I	50.2	6.3	2.9	6.96
II	46.4	9.8	4.3	10.32
III	40.1	14.2	6.0	14.40

Similarly, the vibrated samples were cut with a 3 cm rib in order to identify the tensile strength, water absorption and porosity of various concrete zones.

Table 2

Results of the tests of vibrated concrete

Layer	Compressive strength limit, MPa	Variation coefficient, %	Water absorption according to the GOST (ГОСТ) 12730.3-78, %	Porosity according to the GOST (ГОСТ) 12730.4-78, %
I	44.5	3.5	6.2	14.88
II	43.7	3.6	6.3	15.12
III	43.2	4.1	6.3	15.12

The circular sections were cut into layers, that were used to prepare cube samples with the edge of 2 cm, the strength, water absorption and porosity of concrete of various layers of the circular section were determined using them.

Based on the above data, the research problem was hypothesized and formulated. While calculating and designing centrifuged reinforced concrete structures, significant strength reserves are not considered and can be analytically determined by means of calculation and experimental methods.

2. Calculation and experimental methods for identifying the strength reserves of centrifuged reinforced concrete structures. In order to address the research problem, we set the task of comparing different methods for calculating centrifuged reinforced concrete structures, both existing in the existing guidelines and regulations (СП) and proposed by the authors in compliance with the experimental data [5, 18—20]].

The experimental structures in their circular cross section were variative, i.e., a combination of layers of the same material, with the properties and characteristics different from each other due to centrifugation.

Hence after the integral (generalized) concrete strength of centrifuged reinforced concrete structures of the circular section had been identified, we investigated the differential (layer-by-layer) concrete strength associated with the variability of its structure in the process of centrifugation.

The analysis of the experimental results showed that in accordance with theoretical calculations, the outer layer of the centrifuged circular structure, which is subjected to the maximum centrifugal force, has the greatest strength and the inner layer has the least strength.

The graph of changes in the strength of centrifuged concrete from layer to layer (from the external to the internal one) takes the form of a downward straight with a downward convexity (Fig. 1).

Thus, the substantiation and expediency of the three-layer model of the variatropic structure of the centrifuged structure are experimentally proved.

A significant difference is also characteristic in the elastic moduli of the layers of such a three-layer structure. The concrete of the outer layer has the largest modulus of elasticity whereas the concrete of the inner layer has a minimum modulus of elasticity, which is also indicative of the variability of the structure and the three-layer model of the centrifuged structure (Fig. 2).

The deformation diagrams of centrifuged concrete also vary considerably across the layers thus confirming the variability of the structure of such concrete. Among all of the diagrams, the largest in strength and load-carrying capacity are those of deformation of the outer layer of concrete, the smallest are the diagrams of deformation of the inner layer of concrete. In all of the samples, the averaged indices have deformation diagrams for the middle concrete layer.

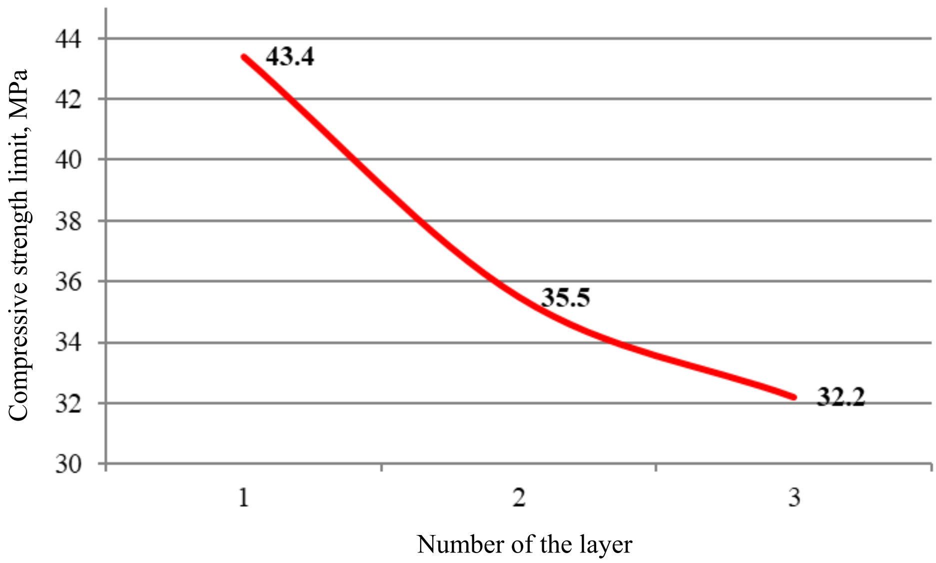

Fig. 1. Distribution of strength and speed of the ultrasound in the layers:
1 is the external one; 2 is the middle one; 3 is the internal one

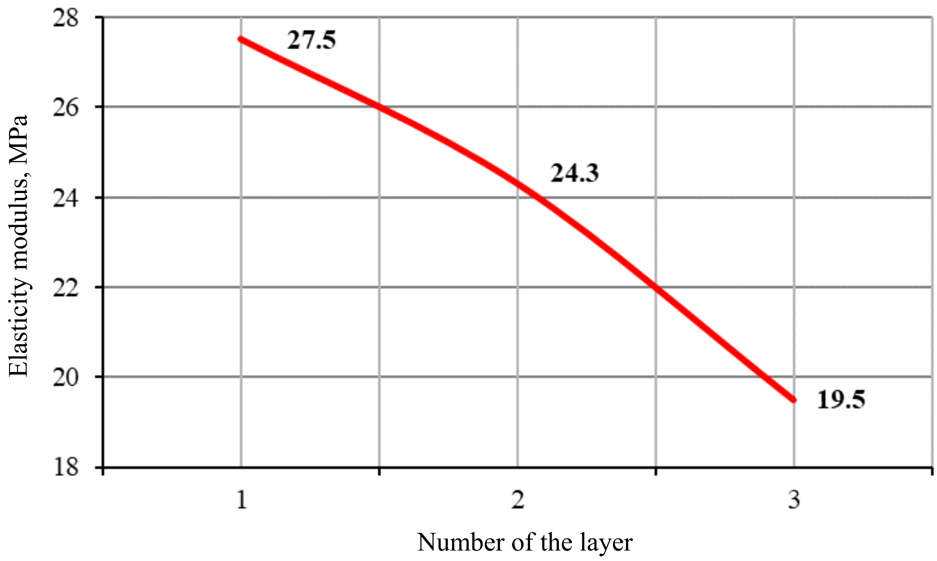

Fig. 2. Changes in the elasticity moduli in the layers:
1 is the external one; 2 is the middle one; 3 is the internal one

In order to compare the calculation methods, a standard centrifuged reinforced concrete column, i.e., a standard serial one, was employed in accordance with the GOST (ГОСТ) 23444

"Racks of Reinforced Concrete Centrifuged Circular Cross-Section for Industrial Buildings and Engineering Structures. Technical Specifications" with the characteristics identified in Table 3.

Table 3

Characteristics of the column according to the GOST (ГОСТ) 23444

Rack label	Main dimensions, mm			Consumption of the materials		Rack weight, ts
	Diameter	Length	Thickness of the wall	Concrete, m^3	Steel, kgs	
C5.48.10-K1	300	4800	50	0.41	51	1.0

The original data for calculating the load-carrying capacity of a typical serial column are presented in Table 4.

Table 4

Original data for calculating the load-carrying capacity of a typical serial column

External diameter D_{cir}	Thickness of the wall B	Length of the rack (column) L
300	50	4800

Concrete class	E_b, MPa	R_b, MPa	Longitudinal reinforcement	R_s, MPa	R_{sc}, MPa	$A_{s,tot}$ 10⌀20
B40	$360 \cdot 10^{-3}$	29	A400	355	355	3140 mm^2

Longitudinal force of vertical loads N_V, kN	Inertia moment of vertical loads M_V, kN·m	Longitudinal force of wind loads N_h, kN	Inertia moment of wind loads M_n, kN·m
200	20	50	15

The calculation of the load-carrying capacity of the centrifuged reinforced column performed in accordance with the method suggested in the regulations and guidelines (СП) yielded the following results:

$$A = \pi(r_2^2 - r_1^2) = 3.14(100^2 - 150^2) = 3.14(10000 - 22500) = 39250 \ \ mm^2; \qquad (1)$$

$$F = R_b \cdot A = 39250 \ \ mm^2 \cdot 29MPa = 113.82 \cdot 10^4 MPa \cdot mm^2. \qquad (2)$$

In order to compare, let us now calculate the load-bearing capacity of the identical centrifuged reinforced concrete column using the integral (generalized) and differential (layer-by-layer) strengths of concrete considering the previously obtained data [5—8].

The load-bearing capacity of the column for the integral strength of concrete is as follows:

$$A = \pi(r_2^2 - r_1^2) = 3.14(10000 - 22500) = 39250 \ \ mm^2; \qquad (3)$$

$$F = R_b \cdot A = 39250 \ \ mm^2 \cdot 32MPa = 125,6 \cdot 10^4 MPa \cdot mm^2. \qquad (4)$$

The load-bearing capacity of the column using the differential strengths of concrete (considering the strength values and the area of each of the three conventional sectional layers, i.e., internal, medium and external ones) is as follows.

The inner layer:

$$A = \pi(r_2^2 - r_1^2) = 3.14(100^2 - 117^2) = 3.14(10000 - 13689) = 11583 \ mm^2; \quad (5)$$

$$F = R_b \cdot A = 11583 \ mm^2 \cdot 32.2MPa = 37.3 \cdot 10^4 MPa \cdot mm^2. \quad (6)$$

The middle layer:

$$A = \pi(r_2^2 - r_1^2) = 3.14(117^2 - 134^2) = 3.14(13689 - 17956) = 13398 \ mm^2; \quad (7)$$

$$F = R_b \cdot A = 13398 \ mm^2 \cdot 35.5MPa = 47.5 \cdot 10^4 MPa \cdot mm^2. \quad (8)$$

The external layer:

$$A = \pi(r_2^2 - r_1^2) = 3.14(134^2 - 150^2) = 3.14(17956 - 22500) = 14268 \ mm^2; \quad (9)$$

$$F = R_b \cdot A = 14268 \ mm^2 \cdot 43.4MPa = 61.9 \cdot 10^4 MPa \cdot mm^2. \quad (10)$$

The total load-bearing capacity using the differential strengths is as follows:

$$F_d = R_{bB} \cdot A_B + R_{bcp} \cdot A_{cp} + R_{bвн} \cdot A_{вн} = 37.3 \cdot 10^4 + 47.5 \cdot 10^4 + 61.9 \cdot 10^4 = \\ = 146.7 \cdot 10^4 MPa \cdot mm^2. \quad (11)$$

The resulting data is summarized in Table 5.

Table 5

Comparison of different methods for calculating the centrifuged reinforced structures

Type of an experimental column	Method for calculating the strength of the column			Differences in the strength Δ, %	
	Calculation using the regulations and guidelines (СП), MPa · mm^2	Calculation using the integral strength, MPa · mm^2	Calculation using the differential strengths, MPa · mm^2	Δ_1, %	Δ_2, %
Centrifuged reinforced column	113.82·10^4	125.6·10^4	146.7·10^4	10.4	28.8

Conclusions. The analysis of the results enabled us to conclude the following.

1. The values of the load-bearing capacity of the centrifuged reinforced concrete column that was calculated in accordance with the regulations and guidelines (СП) using the integral and differential strengths of concrete characteristics were found to differ considerably.

2. The resulting load-bearing capacity of the centrifuged strength column calculated using the integral strength of concrete was found to be 10.4 % higher and the estimated load-bearing capacity calculated using the differential strength of concrete was found to be 28.8 % higher.
3. Therefore by means of the calculation and experimental methods, the latent strength reserves of industrial columns of a variatropic structure manufactured using the centrifugation methods that were not previously considered were identified which are proposed to be further considered by employing the suggested method for calculating the differential strengths of concrete of different layers of columns.

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