Features of change in strength and modulus of elasticity of various layers of vibrocentrifuged fiber-reinforced concrete columns of annular section

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Abstract. Upon carrying out the studies, the authors identified the features of strength and elastic modulus variation of different layers of vibration centrifuged fiber-concrete tubular columns. They provide rationalization for the variational nature of test structures, i.e. combinations of layers, the properties and characteristics of which are different. To reveal the trends of changes in the physical and mechanical properties of a structure by layers, the authors performed a through ultrasonic scanning using a Pulsar 2.2 device. The authors verified the applicability of the described technique for the variational vibration centrifuged structures. Three test cubes used for compression strength determination were produced from each the inner, middle, and outer layers. Confirming theoretical data on centrifugal molding, the authors revealed that the outer layer of the structure, which experienced the maximum centrifugal force, had the greatest strength, and the inner layer had the minimal strength. Substantiation of the fact that the variational vibration centrifuged structure is three-layered was confirmed experimentally.

1. Introduction
Research was conducted in laboratory settings of Don State Technical University, the features of strength and elastic modulus variation of different layers of vibration centrifuged fiber-concrete tubular columns were identified.

Concrete centrifuging is based on the ability of the concrete mix inside a rotating form to tend to the periphery of the form under the action of centrifugal forces and to compact itself. The effect of centrifugal force on coarse aggregate grain is the greater, the larger the radius and average grain density. In this regard, the grains of larger sizes become pressed to the outer surface of the product or structure, and the smaller ones are distributed more closely to the inner surface of the product. For this reason, centrifuged concrete differs from vibrated concrete in that the aggregate grains are non-uniformly distributed throughout the thickness of the product [1-30].

The sections of the test structures were essentially variational in nature, i.e. they were a combination of layers, the properties and characteristics of which differed due to centrifugation. To reveal the trends of changes in the physical and mechanical properties of a structure by layers, the authors performed a through ultrasonic scanning using a Pulsar 2.2 device.

A surface scanning procedure consists in the following. A certain volume ABCD of wall thickness he is separated from the tubular element of an annular section (Figure 1), and a dispersion of the
average concrete mix density over the depth and length of a product is determined. That said, the literature data suggests that the wall thickness should be 1/10D of the cross section diameter, therefore, if the inner diameter of the form under consideration is 165 mm, the wall thickness of the product is taken as 16.5 mm.

Physical and mechanical properties of the molded centrifuged product samples are listed in table 1. The results of surface scanning are given in table 2.

Figure 1. A Study of the Test Cylinder Inner and Outer Diameter Using an Ultrasonic Technique.

Table 1. Physical and mechanical properties of centrifuged concrete samples.

| No. of a concrete sample | Sample weight, g | Sample volume, cm³ | The average density of a sample, kg/m³ | Estimated compression strength, MPa |
|--------------------------|------------------|--------------------|---------------------------------------|----------------------------------|
|                          |                  |                    |                                       | vibrated concrete                |
|                          |                  |                    |                                       | centrifuged concrete              |
| 1                        | 5837.3           | 2308.1             | 2528                                  | 29.1                              |
| 2                        | 5870.8           |                    | 2543                                  | 29.2                              |
| 3                        | 5903.1           |                    | 2557                                  | 30.0                              |
| 4                        | 5789.5           |                    | 2508                                  | 28.1                              |

Table 2. The results of surface scanning by layers.

| No. of a concrete sample | Characteristics of surface scanning rate by layers | Compression strength, MPa |
|--------------------------|---------------------------------------------------|---------------------------|
|                          | outer     | middle | inner     | outer     | middle   | inner     |
| 1                        | 4940      | 4891   | 4741      | 44.2      | 42.9     | 39.4      |
| 2                        | 5110      | 4938   | 4852      | 44.4      | 43.2     | 37.8      |
| 3                        | 5120      | 4938   | 4852      | 45.2      | 44.1     | 41.5      |
| 4                        | 4890      | 4861   | 4684      | 43.0      | 42.1     | 38.3      |

This technique was used on the centrifuged three-layer small-size samples. The authors have verified the applicability of the described technique for the variational vibration centrifuged structures.

2. Experimental program and research results

For this purpose, three prismatic solids were cut out of the wall of each structure with the following dimensions: length – 1000 mm, width – 100 mm, height – 125 mm. The sensors of the device were attached following the pattern shown in Figure 2.
Thus, the sensors were located on all three reference layers (inner, middle and outer) of the variational structure throughout the wall thickness of a section.

Three test cubes used for compression strength determination were also produced from each the inner, middle, and outer layers.

To obtain high-quality concrete, the conditions for the formation of its structure must be studied: the mobility of the concrete mixture, the compaction efforts during molding, and the conditions under which the aging of concrete occurs.

Under the action of centrifugal forces during the centrifugation of the concrete mixture, the aggregate grains move towards the outer surface of the cross section of the core wall, forming a rigid frame glued together with cement paste. In the course of centrifugation, excess cement paste is squeezed onto the internal surface of the cross section, as a result of which a layer of mortar with a very high cement content is formed.

During centrifugation, the aggregate grains form a rigid skeleton of the outer layer of the pipe core. When the movement of the aggregate grains ceases, the cement dough between them is no longer crimped, there is a separation of the concrete mix, which is characterized by a low cement content in the outer layer of the core and significant moisture. This occurs when the fineness of the cement grind is insufficient and large cement particles are poorly hydrated, with the result that the cement paste does not have sufficient viscosity. Such a wet, non-viscous cement paste that cannot glue aggregate grains promotes the sinking or collapse of the main concrete layer during centrifugation.

Good compaction of the concrete mix is achieved by increasing the consumption of cement and reducing the water-cement ratio (WC). However, practice has shown that to achieve the required compaction of the mixture, an increase in the initial content of cement in it is not enough. Larger grains become pressed to the outer surface of the product or structure, while smaller grains are distributed more closely to the inner surface of the product.

For this reason, centrifuged concrete differs from that obtained by vibrating in that the aggregate grains are not uniformly distributed along the height of the product. With a properly selected composition of such concrete on the surface of the wall inside the element is a layer of sludge, followed by cement stone, then fine-grained concrete with a normal texture. In accordance with this, the distribution of cement paste over the cross section of the product or structure also changes. This heterogeneity can reduce the strength properties of centrifuged concretes in comparison with those that should be if the aggregate grains were distributed evenly.

Figure 3 shows that the outer layer of the structure, which experienced the maximum centrifugal force, has the greatest strength, and the inner layer has the minimal strength, which confirms the theoretical data on centrifugal molding.
Figure 3. A Diagram of Strength Factor by Layers of Centrifuged Concrete
1 – outer layer; 2 – middle layer; 3 – inner layer.

The middle layer demonstrates medium strength, however, slightly greater than the arithmetical mean of values of the outer and inner layers.

In other words, the strength diagram by layers of the variational structure will be not an ascending straight line, but an upwards-convex curve (Figure 4).

The proposed physical model characterizes the features of the distribution of the components of a concrete mix during vibration centrifugation depending on their size and the ratio of aggregate and cement paste.

Figure 3. Strength Diagram of Concrete Layers of the Variational Structure
1 – outer layer; 2 – middle layer; 3 – inner layer.

3. Conclusion
The substantiation of the fact that the variational vibration centrifuged structure is three-layered is, therefore, confirmed experimentally.

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