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Technology of Forming Tubular Concrete Columns

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Abstract

Introduction. In manufacturing tubular concrete columns, attention should be paid to a technology of filling a steel tube with a concrete mixture. In practice when a concrete mixture is being fed into a tube from the top, a proper quality of concreting a structure is not guaranteed. In this study, the aim was to test the effectiveness of a technology of forming columns with a self-sealing concrete mixture by means of pressure concreting.

Materials and Methods. Experiments to study the effectiveness of the suggested technology for forming a tubular concrete column with a saturated content of longitudinal and spiral reinforcement were conducted on a transparent model. A self-compacting mix composition was selected that ensured the required workability, flowability, homogeneity, and absence of stratification. Through the course of the experiments, the process parameters were adjusted with the speed of filling the structure with the concrete mixture as the most important one. The uniformity of concrete distribution throughout the model was monitored.

Research Results. The experiment indicated that the concrete mixture easily reached all of the areas of the structure with no loss of quality. No air bubbles were observed on the surface of the structure, indicating high-quality compaction of the mixture. Concrete strength and density variations in the upper, middle, and lower zones of the structure were minimum. The resulting concrete is characterized by a homogeneous structure, with a uniform, evenly distributed composition with no significant voids or inhomogeneities throughout the entire volume.

Discussion and Conclusion. The absence of formwork, scaffolding, and other equipment, high speed of concreting significantly reduce the time and labor intensity of column installation. All of these, combined with the achieved concrete quality, open up avenues for a broad-scale use of the pressure concreting method in construction projects in the Russian Federation. Further work is needed in order to develop a method for ultrasonic quality control of concrete in tubular concrete columns.

Keywords: tubular concrete columns, self-compacting concrete, method of ascending concrete mixture, strength and density of concrete, homogeneity of a structure

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Технология формирования трубобетонных колонн

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Аннотация

Введение. При изготовлении трубобетонных колонн следует обратить внимание на технологию заполнения стальной трубы бетонной смесью. Практика показывает, что при подаче бетонной смеси в трубу сверху должно качество бетонирования конструкции не гарантируется. В данном исследовании ставилась цель опытной проверки эффективности технологии формирования колонн самоуплотняющейся бетонной смесью методом напорного бетонирования.

Материалы и методы. Эксперименты по исследованию эффективности предложенной технологии формирования трубобетонной колонны с насыщенным содержанием продольной и спиральной арматуры проводились на прозрачном макете. Подобран состав самоуплотняющейся смеси, обеспечивающий требуемую удобоукладываемость, текучесть, однородность и отсутствие расслоения. В ходе экспериментов подобраны технологические параметры формирования, среди которых наиболее важным была скорость заполнения конструкции бетонной смесью. Контролировалась равномерность распределения бетона по всему макету.

Результаты исследования. В результате эксперимента выявлено, что бетонная смесь легко достигала всех зон конструкции без потерь качества. Наблюдалось отсутствие выделения воздушных пузырей с поверхности конструкции, что свидетельствует о высоком качестве уплотнения смеси. Разброс прочности и плотности бетона в верхней, средней и нижней зонах конструкции минимальный. Полученный в конструкции бетон характеризуется однородной структурой, имеющей однородный, равномерно распределенный состав без значительных пустот или неоднородностей по всему объему.

Обсуждение и заключение. Отсутствие опалубки, подмостей и прочих приспособлений, высокая скорость бетонирования значительно снижают продолжительность и трудоемкость монтажа колонн. Все это, в совокупности с достигнутым качеством бетона, открывает хорошие перспективы для широкого применения метода напорного бетонирования в строящихся объектах в РФ. В дальнейшем необходимо разработать методику ультразвукового контроля качества бетона трубобетонных колонн.

Ключевые слова: трубобетонные колонны, самоуплотняющаяся бетонная смесь, метод восходящей бетонной смеси, прочность и плотность бетона, однородность структуры

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Introduction. Tubular concrete columns (TBCs) are increasingly used in designing frames of high-rise buildings in the Russian Federation. This is due to a number of significant advantages of the economic, technological, constructive plan, as well as the architectural expressiveness of these structures [1–6]. One of the restraining factors for the broader use of TBCs in this country is the insufficiently developed technology of filling steel tubes with a concrete mixture. Due to the considerable length of steel tubes with a relatively small diameter, which provide "non-removable formwork" for columns on two or three floors or higher, traditional technologies for filling them with a concrete mixture from the top fail to ensure proper concreting quality. It is fairly challenging to ensure and control the quality of laying and compaction of a concrete mixture under such conditions.

According to Japanese builders' experience that are among the leaders in the volume of TBC applications, the most promising technology for their molding is use of the ascending concrete mixture method also known as the pressure concreting method where a concrete mixture is pumped with a concrete pump under pressure through a specially made hole in a steel tube from bottom to top.

[7, 8] have shown that this concreting technology reduces the number of air bubbles in the contact layer of reinforcement with concrete. The resulting concrete layer under the reinforcement was characterized by a better

quality compared to the traditional concreting on top of the mold leading to an increase in the adhesion of reinforcement to concrete.

In order to ensure the necessary high plasticity and mobility, self-sealing concrete mixtures (SSCMs) should be employed. Such mixtures started being used overseas in the last century, but are currently broadly used in this country [9–11]. The use of SSCMs allows one to attain a number of other positive results with the most important ones being:

- no need for vibration during installation;
- no delamination of the mixture;
- reduction in the cement content;
- high strength, density and durability of concrete.

The aim of the study was to test the effectiveness of the technology of forming TBC columns using substructures by means of pressure concreting.

Materials and Methods. At the first stage, the composition of the SSCMs was selected and its quality was checked. To this end, the workability of the mixture was monitored by means of an Abrams cone and the fluidity was identified using the locking ring method. The second method was employed in order to evaluate the capacity of the mixture to penetrate into narrow spaces, including gaps between reinforcing bars, with no delamination or clogging.

Sampling for identifying the normalized parameters of the mixtures was carried out in compliance with GOST R 59715 "Self-Sealing Concrete Mixtures. Testing Methods" taking the instructions of GOST 10181 "Concrete Mixtures. Testing Methods" into consideration.

Concrete strength was monitored based on the results of compression tests of control samples-cubes with a rib size of 100 mm at the age of 3, 7, 28 days in compliance with GOST 18105 "Concretes. Rules for Strength Control and Assessment", GOST 10181 and GOST 31914 "High-Strength, Heavy and Fine-Grained Concretes for Monolithic Structures. Rules for Quality Control and Assessment".

When a mixture of the required quality has been obtained, model experiments on molding the product were performed on a large-scale transparent model of a tube-concrete column (Fig. 1). The model of the tubular concrete column had a height of 1973 mm and a diameter of 300 mm. The shell tube was made of plexiglass. The reinforcement frame was made of 7 longitudinal rods with a diameter of 25 mm and a spiral of rods with a diameter of 8 mm with a pitch of 50 mm. Additionally, two longitudinal rods with a diameter of 25 mm are installed in the lower part of the reinforcement frame with a light distance between them and the remaining rods of 30 mm. That allowed assessment of the penetration ability of SSCMs between the rods of densely reinforced TBCs.



a)



b)

Fig. 1. TBC sample: a — general view of the layout for testing the WBS method; b — location of core drilling

In order to supply the concrete mixture, a 125 mm diameter concrete duct system was employed that is connected to the layout with special quick-release fittings. The mixture was supplied by a Cifa PC 709 concrete pump. 72 hours after forming the reinforced concrete core, cores were extracted from the mock-up for them to gain concrete strength under natural conditions. The cores were drilled from four sites located at the bottom, top and in the middle zones of the layout (Fig. 1b).

Concrete strength was monitored at the age of 28 days based on the results of compression tests of cylinders with a diameter of 100 mm and a height of about 100 mm in accordance with GOST 28570 "Concretes. Methods for Identifying Strength Based on Samples Selected from Structures" and GOST 31914.

Research Results. The results of identifying the workability of SSCMs by the size of the spreading diameter of a standard cone and the spreading time up to a diameter of 500 mm are shown in Tables 1, 2 and in Fig. 2.

The resulting mixture is highly stable. The cement paste and water did not separate from the aggregate along the circumference of the spread, and there were no signs of delamination of the concrete mixture. The time to stop blurring is 62 seconds. The contours are clear. The mixture was dense and homogeneous throughout the entire test until the installation was completed. Workability retention is 180 min long.

The compressive strength of concrete control samples of cubes according to the results of the cube strength control corresponds to class B70.

Table 1

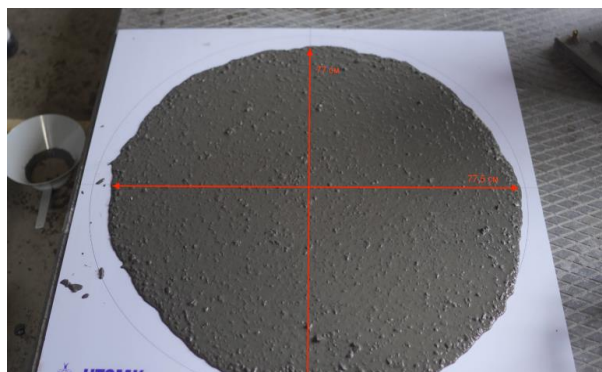
Results of control of workability of the mixture

Composition number	Time t_{500} , sec	Diameter of the spread, cm			Spread grade	Viscosity grade
		d_1	d_2	d_{cp}		
#1	3	77.5	77	77.25	PK3	V2

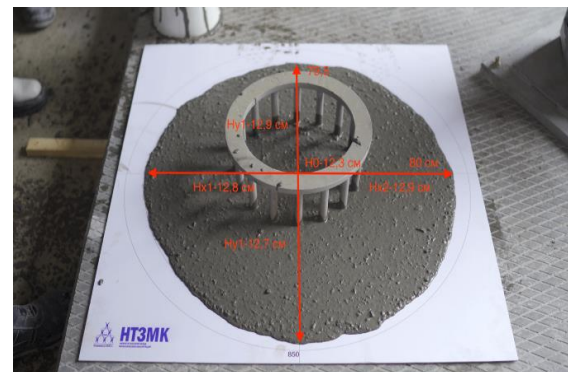
Table 2

Results of the cone spreading control in the locking ring

Composition number	Diameter of the spread, cm			Measured heights, cm					Fluidity grade
	d_1	d_2	d_{cp}	h_0	h_{x1}	h_{x2}	h_{y1}	h_{y2}	
#1	80	79.5	79.75	12.3	12.8	12.9	12.9	12.7	T4



a)



b)

Fig. 2. Test results of the concrete mixture: a — identifying spread, viscosity grades; b — identifying fluidity grades

The results of forming the TBC layout are as follows. The time of filling with the mixture is 42 seconds long, the filling speed is 229.5 liters/min. As the TBC layout was being filled, it was important to ensure an even distribution of concrete throughout the entire volume of the structure. Visual observation of the filling process through transparent walls showed that the mixture started rising inside the reinforcement frame, but when a height difference of more than 50 mm

had been reached, it spread along the peripheral zones of the structure. The mixture easily reached all of the areas with no loss of quality. At the end of the concreting process, there was no release of air bubbles from the surface of the structure, which is an indication of a high quality of compaction of the concrete mixture. The condition of the outer surface of the reinforced concrete core is shown in Fig. 3.

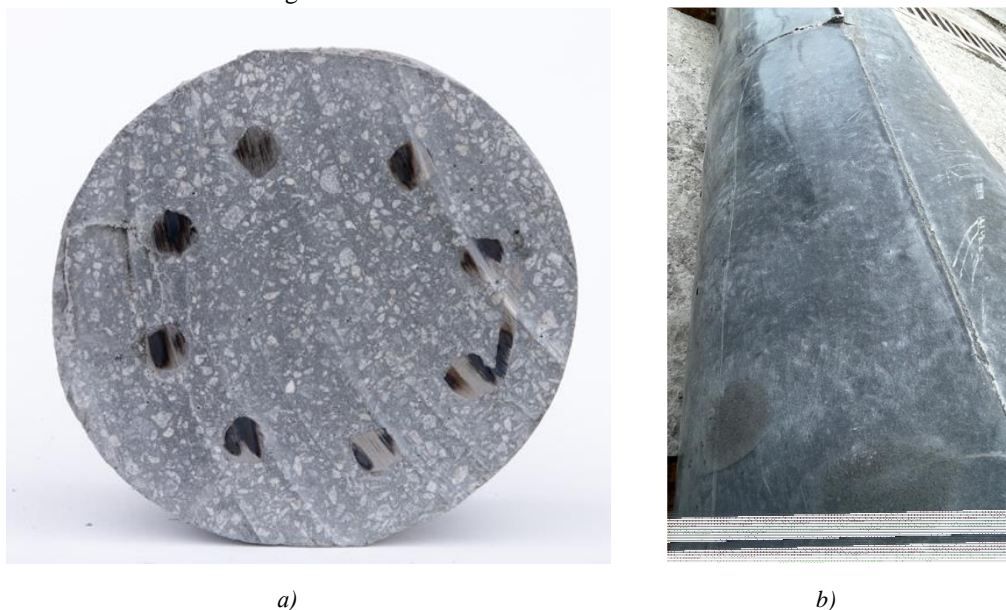


Fig. 3. Concrete compaction quality: *a* — reinforced concrete core in section; *b* — lateral surface of the reinforced concrete core

According to the test results of four cylinders, the compressive strength of concrete ranged from 77.9 MPa to 81.2 MPa. The density of the samples was also in a very narrow range, from 2549 kg/m³ to 2588 kg/m³. Such results are indicative of the absence of stratification of the mixture and uniform distribution of aggregates over the entire volume and height.

Discussion and Conclusion. The research has shown that the WBS method is capable of delivering good-quality molding and compaction of TBC concrete. The thixotropic behavior of the SSCMs reduces the viscosity of the mixture and counteracts its segregation due to shear stress during the continuous movement of the mixture in the volume of the structure under the pressure of the updraft. As a result, a high uniformity of concrete is attained in the structure including its height. The variation in strength and density of concrete in the upper, middle and lower zones of the structure is minimal.

For TBCs, which are more broadly used in frames of high-rise buildings, the uniformity of concrete throughout the entire volume of the element is no less significant than its absolute strength. Heterogeneity leads to local stress concentrations and a decrease in the overall load-bearing capacity of the structure, which might negatively affect the mechanical safety of the building as a whole.

It should be noted separately that in calculating the strength of pipe-concrete columns concreted by means of this method, it is not necessary to apply the coefficient of working conditions $\gamma_{b3} = 0.85$ to the calculated compressive strength of concrete (Section 6.1.12 of SP 63.13330.2018 "Concrete and Reinforced Concrete Structures. Basic Provisions"). Combined with a possibility of practical use of low strength variability (in identifying the concrete class), it makes it possible to obtain higher calculated values of compressive forces in concrete structures. As a result, significant improvements of the technical and economic performance of the columns become possible.

The studies allow us to conclude that it is advisable that the TBC molding technology is employed using the WBS method when a self-sealing concrete mixture inside a steel pipe is pressurized from bottom to top.

Let us note the obvious advantages of the method over the traditional ones with a mixture feed from the top:

- a significant reduction in the possibility of capturing additional air inside the substation;
- practical exclusion of a possibility of segregation of the mixture due to impacts on the reinforcement and the walls of the formwork tube during free fall;
- a significant reduction in the filling time of the structure;
- exclusion of the formation of working seams and operations with their organization;
- a reduction of construction installation time;
- a reduction in the number of workers on the construction site;
- eliminating the need to make use of scaffolding, ladders, and ladders.

The concrete obtained in the structure is characterized by a homogeneous structure with a homogeneous, evenly distributed composition with no significant voids or inhomogeneities throughout its volume. It becomes possible to obtain higher values of the calculated resistance of concrete compared to concrete of the same composition, but molded by means of the traditional technologies.

However, due to the lack of regulatory documents with recommended values of technological parameters of molding for the VBS method (upper and lower limits of the filling rate of concrete blocks, diameters of concrete pumps, overpressure values), it is advisable that broader comprehensive studies are conducted in the area. For construction practice, it is also essential to develop a methodology for ultrasonic quality control of concrete in columns.

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AL Krishan: scientific supervision, analysis of research results, revision of conclusions.

VV Parfenov: formation of the main concept, goals and objectives of the study.

NV Vavilin: calculations, text preparation.

MA Astafeva: text revision, analysis of results, formulation of conclusions.

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