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Strength characteristics of load-bearing reinforced concrete structures of the Ostankino television tower

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Abstract. The article describes the design features of the Ostankino TV tower in Moscow. The main results of the earlier works of the load-bearing reinforced concrete structures of the TV tower column and foundations are presented in the article. The authors examined the internal and external surfaces of reinforced concrete structures of the entire height of the tower with selective defectoscopy and determined the actual strength of concrete by non-destructive methods. The figures of this work show the main structural reinforced concrete elements and a distribution graph of strength characteristics of the height of the structure. Despite the noticeable height changes, the concrete strength in all parts exceeds the value provided for in the project.

1 Introduction

The main load-bearing structures that provide the strength and stability of the tower are its reinforced concrete column, support part, leg supports and foundation.

The main structure is a monolithic prestressed reinforced concrete column, where a metal antenna part is bounded with horizontal diaphragms at a height of 385.5 m. The column is monolithically coupled with a support part in the form of a conical shell with a bent generatrix at height of 63 m; at 17.3 m it turns into 10 leg supports. These supports are based on a monolithic prestressed main foundation made in the form of a closed decagonal ribbon of 9.5 m width, 3 m height and a depth of designed main foundation. External structures are fastened cantilevered to the outer surface of the column, with the embedded parts and metal elements: building up, viewing platforms, technological balconies. A steel lattice structure is located on a separate foundation inside the column and the supporting part; it is connected to the inner surface of the column by spacers and perceives only vertical loads [1] (Fig. 1, 2).

The prestressed column and the support part are made with 149 open inside ropes [2], its lower parts are connected through anchorage with horizontal reinforced concrete diaphragms at 43 m and 63 m. The foundation is prestressed from the outside with wire reinforcement tension at concrete at each of the ten straight sections.

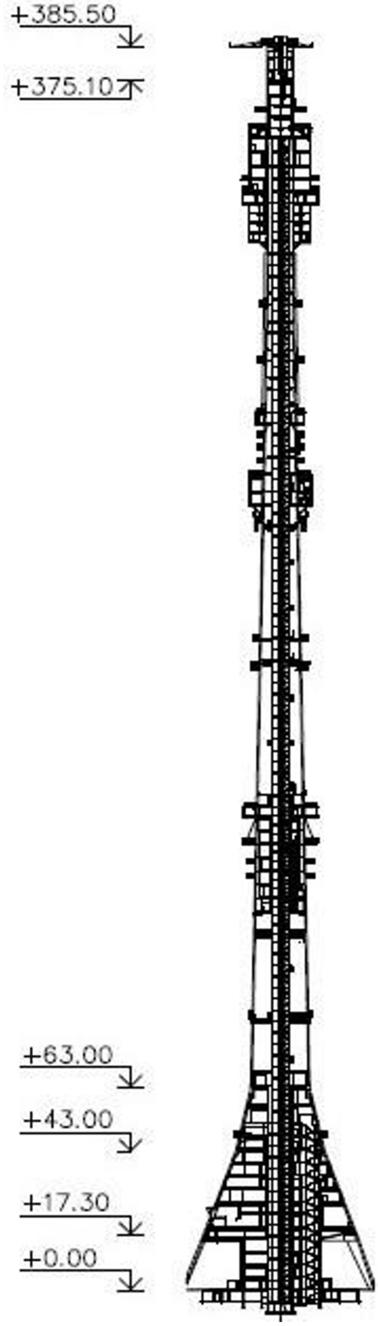

Fig. 1. Section of the reinforced concrete part of the Ostankino TV tower.

A unique structure was created thanks to the talent and professionalism of the designers and engineers. The Tower shows the reliability of safe operation for more than half a century, even in extreme conditions (such as the fire in 2000 and regular hurricane winds).

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It should be said that the materials used and the successful design solutions are both important and it helps to ensure the durability of the structure. Also, the long-term successful operation of the TV tower would be impossible without use of special concrete. A special durability and the increased strength of the structure must also be provided. It exceeds the minimum one hundred-year service life required in the norms recommended by GOST 27751 for unique structures. Research in the field of improving the reliability and durability of building structures of buildings and structures operated, including in aggressive environments, subjected to fires or other beyond-design influences, remains important and relevant at the present time, which is confirmed by the research of a number of well-known scientists, the results of which have been published in recent years [3-15].

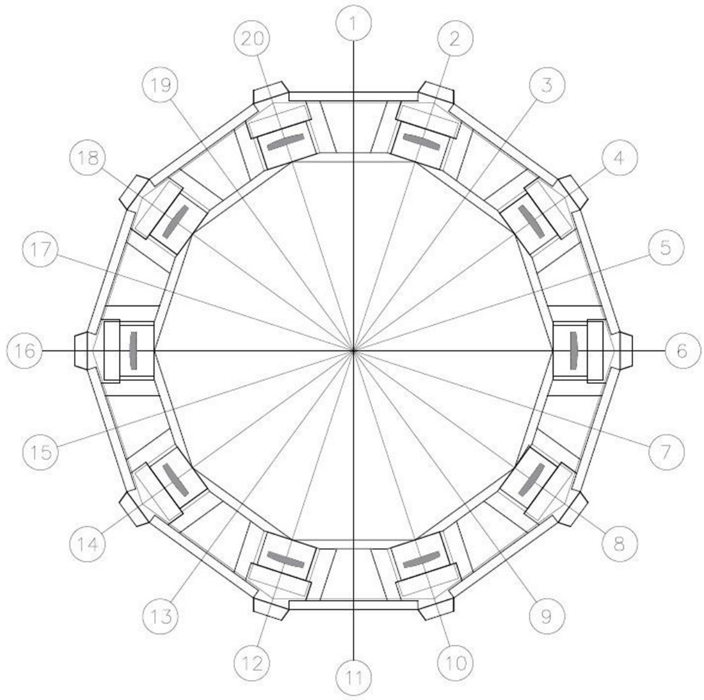

Fig. 2. Plan of the main foundation of the Ostankino TV tower

A special frost-resistant concrete was designed for the tower in the VNIPI Teploproekt Minmontazhspecstroj of the USSR. This concrete is strong and durable, it resists not only low temperatures, but other atmospheric effects and fire.

The concrete was designed on the basis of the study of the influence of the water-cement ratio with plasticizing chemical additives on the mechanical properties and durability of cement stone. The so-called high- functional concrete of the XXI century (High Performance Concrete) was used as a basis. It is characterized by increased workability in the formwork with a significant reinforcement content, low water absorption, high resistance and corrosion resistance in aggressive environments. It also has high strength (up to B60), frost resistance (up to F500), high density that provides water resistance up to W10 [16].

A complex of studies with tests for frost resistance was also performed. It revealed the influence of winter concreting and the so-called "cold joints" with breaks in concreting for more than 8 hours, etc. [17].

The suppliers and the quality of used materials, the manufacturing technology, laying the concrete mixture and the care of concrete hardening were strictly controlled during the construction process. At the same time, the cube samples of 150x150x150 mm were made and tested for concrete quality control during construction; they were left in the open air at various heights of the tower for future tests to identify long-term operation for the concrete properties.

It is considered that the Ostankino tower is located within an aggressive air environment, so, in 1972 and 1985, the reinforced concrete outer surfaces of the column, the supporting part and the leg supports were hydrophobized with 5 per cent solution of hydrophobic organic silicon liquid GKZH-94. In 2004...2005 the surfaces was hydrophobized with the composition "SILOR MAX" with an impregnation depth of 1.5-2 mm[18].

Taking into account the special responsibility of the object, the soil of the base and structures of the TV tower is regularly monitored after the construction. Specialized organizations regularly performed visual and instrumental surveys of the technical condition of individual elements and the structure as a whole.

Extraordinary surveys were conducted and recommendations for eliminating the consequences were worked out after the fire in 2000.

The damages of reinforced concrete structures included chips of the protective layer of concrete up to 4 cm deep in the inner surface of the column, new cracks, 120 prestressed ropes lost the operability [19].

The internal sections of the reinforced concrete column damaged by fire were restored in 2001. The ropes that lost their bearing capacity were partially replaced and tensioned. 120 ropes was tensioned in March 2003; other 26 ropes were installed and tensioned in April-October. Two more ropes broke off during the planned ropes tension in 2005 and in 2008; as a result 144 ropes are tensioned to date [20].

The ropes are tensioned by special fasteners to the embedded parts installed in the column to follow the tower column when it is deflected. Subject to the project, these fasteners are installed at 2218 embedded parts. The results of observation of the tower structures in 2006 showed that fasteners were not installed at 1209 parts; there was no access to 137 parts, 267 embedded parts were missing. The ropes touched metal beams at 26 points, ceilings at 8 points. At 141 points, the ropes were shifted from the fastening points, at 7 points up to 30 cm.

The concrete strength at different levels of the column was determined by non-destructive survey methods. In general, the concrete strength is not less than the designed 400 kg/cm2. At the lower levels – 600 kg/cm2 and more, starting with +300.0 m, the decrease was 420-450 kg/cm2 to +374.8 m and higher.

The strength concrete of single parts of the tower column at a height +381.4 m is reduced to 360-385 kg/cm2, but on average within this height is 415 kg/cm2. The actual concrete strength of the reinforced concrete diaphragm at a height +384.0 m is not less than the designed and is 450 kg/cm2.

The concrete strength of reinforced concrete cantilevers for the support of sleeve anchors of prestressed ropes is not less than the designed strength and is 450 kg/cm2.

For the upper part, the class B32 is used for calculations, for the lower part – B40 [19].

The waterproofness of concrete was studied by the employees of the MGSU and the RTRS operation service several years after the last coating with a hydrophobic composition subject to the GOST 12730.5-84. It is based on the direct measurement of the air permeability of concrete, which characterizes the relative density of the surface layer of concrete and is an indirect indicator of its waterproofness. Control measurements were also performed for cubes stored at a height of 47 m. The measurements results showed that:

- the tower surface at 48 m height has the least average density along the perimeter. The average mc=6.56s/cm^3 has a minimum value;

- the conical part of the tower (lower the 63rd height mark) has the less surface density than the column ofthe tower;
- along the perimeter of the tower, the least density is the surface to the southeast, the average dac=8.82s/cm^3, and the most – to the north, dac=16.88 s/cm^3;
- the average density of the outer surface of the concrete of the tower is 3 times greater than the density ofnot covered samples;
- the density of the inner surface of the tower supports (da_c=40.54 s/cm^3) is more than the density of theouter surface of the supports (da_c=9.7 s/cm^3) [17].

2 Methods

The authors examined the main load-bearing structures of the tower in 2020; it included determining the technical condition, the concrete strength of the main foundation and aboveground structures at various heights of the structure and the water resistance of the foundation concrete [21].

The technical state was determined with a visual inspection inside and outside and an instrumental determination of the geometric parameters of cracks.

The width of the crack opening was measured with MPB-2 microscope, the depth was measured with a Pulsar 1.2 defectoscope.

The concrete strength was determined by non-destructive testing methods: ultrasonic, with the Pulsar 1.2 defectoscope and the elastic rebound method with the ONYX-2.5 electronic sclerometer.

Two batches of samples were tested in laboratory conditions with a PGI-1000 hydraulic press – three cubes stored at 153 m and three cubes at 365 m – to assess the strength of the control cubes made during theconcreting of the column and stored in the open air at various heights of the tower, to establish the basic dependence for the Pulsar 1.2 and ONYX-2.5 devices.

3 Conclusions

Defects and damages were not found when conducting surveys from two dug pits. They can reduce the bearing capacity of the reinforced concrete foundation and its deviations from the design dimensions. The average concrete strength determined by the elastic rebound method was 41.51 Mpa, it corresponds to the concrete class B33, from the outside – 45.66 Mpa (B36). The water resistance of concrete determined during the surveys was W14 and W10, respectively. A protective layer thickness of more than 75 mm is sufficient to provide the necessary corrosion-resistant foundation.

The average strength subject to the test results for the first batch of cubes stored at 153 m was 45.1 MPa for the second batch, starting from 365 m and higher was 38.9 MPa.

More than one and a half thousand tests at different heights of the TV tower, from the inner and outer sides of the reinforced concrete column was performed to obtain a complete picture of the strength distribution of concrete of aboveground structures, each of the above methods.

The concrete strength determined during the tests and the corresponding percentages of variation are presented in the form of a graph in Fig. 3.

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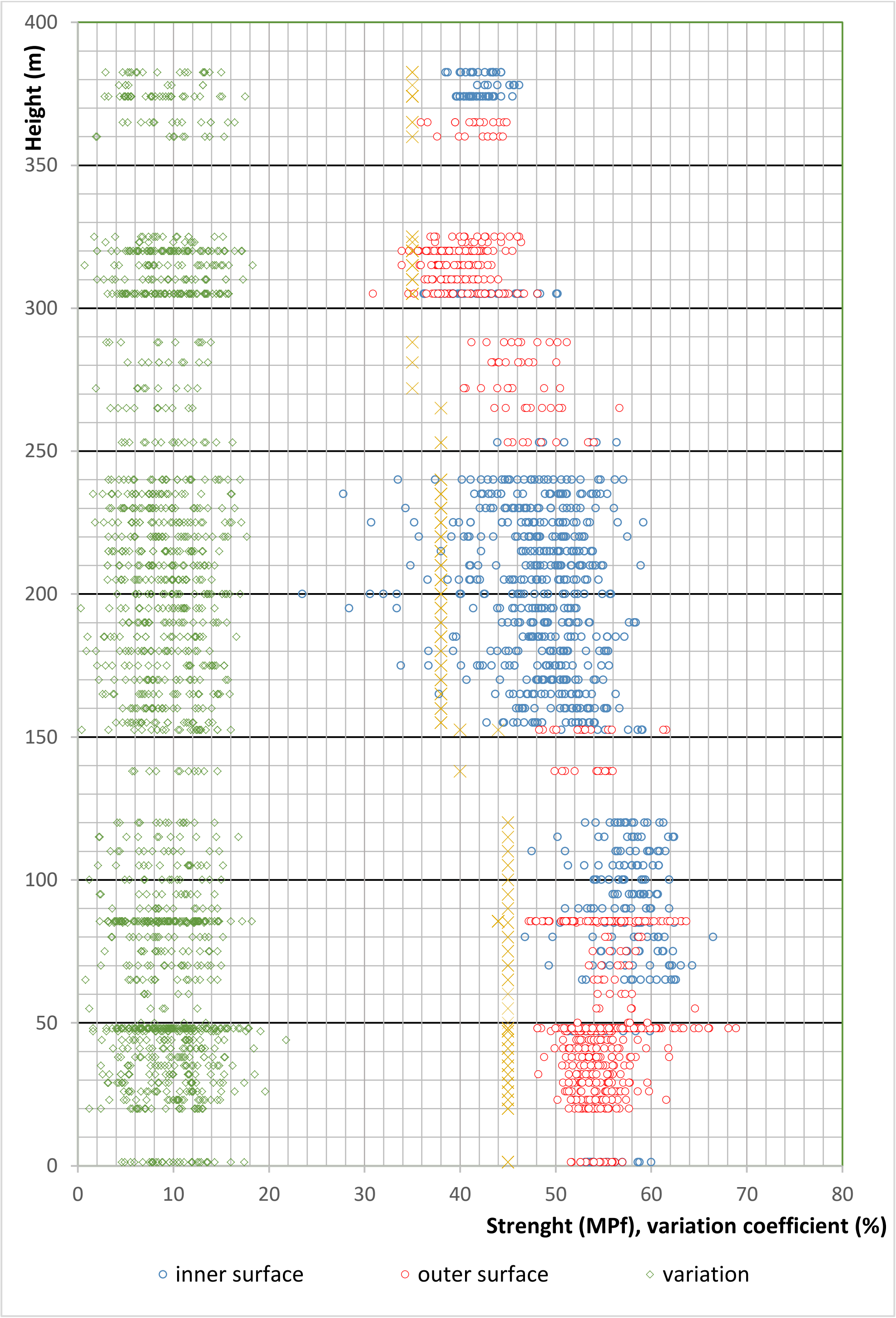

Fig. 3. The results of concrete strength measurement

The graph shows that the strength of concrete decreases with the height of the location of the studied points, which is consistent with both the results of previously conducted tests [19] and with the tests of two batches of cubes. In general, the strength of concrete in all sections of the tower height exceeds the strength of M400 concrete, which is provided for in the project, and up to the 300m mark this excess is noticeably greater. At the same time, in contrast to the decrease in the air tightness of the surface layer of concrete noted in [17], there is no decrease in the strength determined on the outside of the column compared to the inside. Thus, it can be stated that the observed differences in strength in height are explained not by different intensity of external atmospheric influences, but by different characteristics of the laid concrete, or by the influence of early loading, which, according to [22], leads to an increase in its strength.

References

1. N. V. Nikitin, *Ostankino Television Tower.* (Strojizdat, Moscow, 1972), 215 p.
2. V.I. Travush, Vestnik NIC «Stroitel'stvo» **1 (16)**, 126-132 (2018)
3. A.G. Tamrazyan, Reinforced Concrete Structures, **1(1)**, 5–18 (2023)
4. A.G. Tamrazyan and L.A. Avetisyan, IOP Conference Series: Materials Science and Engineering, **365 (5)**,052034 (2018)
5. A.G. Tamrazyan and L.A. Avetisyan, MATEC Web of Conferences, **86**, 01029 (2016)
6. N.N. Trekin, A.N. Mamin, D.N. Trekin, J. Onana and E.N. Kodysh, AMERICAN CONCRETE INSTITUTE, ACI SPECIAL PUBLICATION, 2nd international workshop on durability and sustainability of concrete structures, DSCS 2018 (2018)
7. A.I.Demyanov and V.I. Kolchunov, JOURNAL OF APPLIED ENGINEERING SCIENCE, **15 (3)**, 381386(2017)
8. V.I. Kolchunov and S.YU. Savin, Magazine of Civil Engineering, **4**, 73-80 (2018) DOI: 10.18720/MCE.80.7.
9. V.I. Travush, N.I. Karpenko, VL.I. Kolchunov, S.S. Kaprielov, A.I. Demyanov, S.A. Bulkin and V.S. Moskovtseva, Structural mechanics of engineering constructions and buildings, **16 (4)**, 290-297 (2020) DOI: 10.22363/1815-5235-2020-16-4-290-297
10. V.I. Kolchunov and N.B. Androsova, IOP Conf. Series: Materials Science and Engineering, **463**, 032067 (2018) DOI:10.1088/1757-899X/463/3/032067
11. V.S. Fedorov, VL. I. Kolchunov, A.A. Pokusaev and N.V. Naumov, Russian journal of building construction and architecture, **4 (44)**, 6-27 (2019) DOI: 10.25987/VSTU.2019.44.4.001.
12. S.O. Kurnavina and I.V. Tsatsulin, Journal of physics: conference series, international scientific conference on modelling and methods of structural analysis 2019, MMSA 2019, **1425**, 012037 (2020) DOI: 10.1088/1742-6596/1425/1/012037
13. A.N. Malakhova, Procedia Engineering, **153**, 439443 (2016) DOI: 10.1016/j.proeng.2016.08.148
14. P.A. Radchenko, S.P. Batuev, A.V. Radchenko, V.S. Plevkov and K.L. Kudyakov, JOURNAL OF PHYSICS: CONFERENCE SERIES, **774 (1)**, 012065 (2016) DOI: 10.1088/1742-6596/774/1/012065
15. A. D. Istomin and T. A. Nazarov, J. Phys.: Conf. Ser., **1425**, 012082 (2019) DOI: 10.1088/1742 6596/1425/1/012082
16. A.B. Trinker, Tekhnologii betonov **9-10**, 52-55 (2017)
17. N. V. Nikitin, *The highest in the world. "Construction and Architecture"* (Izdatel'stvo Novoe v zhizni,nauke, tekhnike, Moscow, 1969), 46 p.
18. A.A. Stupakov and P. E. Razin, Vestnik MGSU **3**, 218-226 (2011)
19. Technical report of the survey results of the state of the reinforced concrete structures of the Ostankino television Tower after the fire and recommendations for their restoration. GUP «NIIZHB», 2000.

20. The report on the rendering of technical services to support observations of the structures of the Ostankinotelevision tower and the issuance of recommendations for its further operation. OAO «ENPI», 2011.
21. V. I. Travush, A. N. Mamin, E. N. Kodysh, V. V. Bobrov and T. V. Dolgova, Promyshlennoe i grazhdanskoe stroitel'stvo **3**, 31-36 (2021) DOI: 10.33622/0869-7019.2021.03.31-36.
22. A. H. Baiburin, Reinforced Concrete Structures, **2(2)**, 13–21 (2023)