УДК [691.3 +669.14]: 621.643

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STRENGTH AND STABILITY OF MODELS OF TUBE-CONCRETE AND REINFORCED CONCRETE COLUMNS

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Key words: pipe concrete, composite materials, destruction, loss of stability, triaxial compression of concrete.

The results previously obtained and published by the authors in various publications are summarized. The general normative method of calculation of reinforced concrete and concrete filled steel tube structures is analyzed, the necessity of carrying out model and field experiments describing deformation, destruction and loss of stability of compressed tube concrete structures is justified. The presence of mutual reinforcement of the components of the system is revealed, which leads to a nonlinear increase in load-bearing capacity, which is characteristic of composite materials actively used in various technical systems.

Introduction. In recent decades, large-sized concrete-filled steel tube structures have been widely used in underground and hydraulic engineering buildings. The use of tubes as a fixed formwork, as well as a casing that limits the ability of concrete to collapse in the transverse direction, turned out to be very effective and capable of increasing the bearing capacity by tens of percent. Nevertheless, the use of concrete-filled steel tubeelements in ground construction is very uncommon and is limited mainly to high-rise buildings. The characteristic cross-sectional size in such structures is rarely less than 1000 mm, which drastically limits the use in industrial and civil facilities - such material costs turn out to be extremely high. The study of the properties of concrete-filled steel tube structures, as well as the behavior of concrete-filled steel tube elements of significant diameters under the influence of various kinds of loads in the world scientific community is given great attention [1–14].

Unlike their predecessors, the authors of the article believe that the use of concrete-filled steel tube structures with small-sized (up to 500 mm) sections can be extremely effective if the list of requirements includes the following at the same time:

1) maintaining increased bearing capacity;
2) resistance to the accumulation of damage and micro-defects of various nature;
3) impact resistance;
4) damping properties, resistance to resonance.

Metal structures that are most widely used in industry correspond to points 1-3. However, non-compliance with point 4 is a clear disadvantage of metal structures, which in some cases leads to a global rise in cost.

Concrete and reinforced concrete structures, in turn, noticeably lose on points 1-3, while having significant damping properties.

In conditions of heavy production with the presence of heavy dynamic modes of operation, all four listed points are important, so the use of concrete-filled steel tube structures is an urgent task.

Despite the advantages of concrete-filled steel tube, there is currently no regulatory framework and calculation methods. Existing documents do not always clearly reveal the issue of the internal static indeterminacy of a concrete-filled steel tube section, the problems of concrete and metal adhesion, and the stability of elements even under static loading. Despite the designated "dynamic" scope of these structures, stability studies should be based on static tests.

Articles [15] are devoted to the study of the stability of small-sized concrete-filled steel tube specimens. As a rule, the question of the influence of the length of the element on the values of critical loads remains unclear. The problem of buckling in engineering is inextricably linked with the buckling coefficients. Therefore, now there is no solution to the classical Euler problem on the stability of a rod if the rod section is composite.

Considering the above, conducting experiments to study the strength and stability of concrete-filled steel tube rods is a topical subject for scientific research. It can lead to the development of effective engineering methods for calculating and designing structures of this type.

Test preparation. The object of the research are specially made specimens from various combinations of steel and concrete materials: concrete (fig. 1*a*), reinforced concrete with flexible reinforcement (fig. 1*b*), non-reinforced concrete-filled steel tube (fig. 1*c*), reinforced concrete-filled steel tube (fig. 1*d*). The diameter of the specimens is 76 mm, the length of the specimens is 100 mm.

Additionally, reinforced concrete and reinforced concrete-filled steel tube specimens 700 mm long were made to study the issues of buckling.

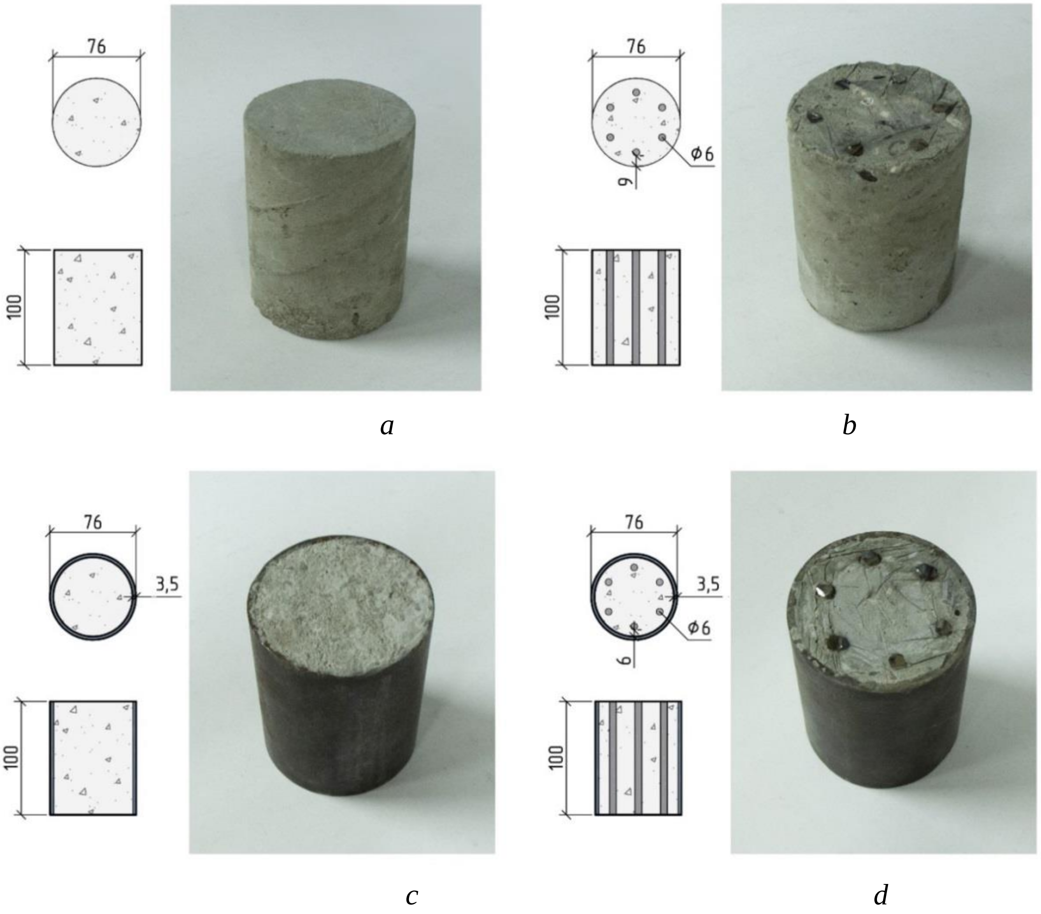


Fig. 1. Made specimens: *a* – concrete; *b* – reinforced concrete; *c* – non-reinforced concrete-filled steel tube; *d* – reinforced concrete-filled steel tube

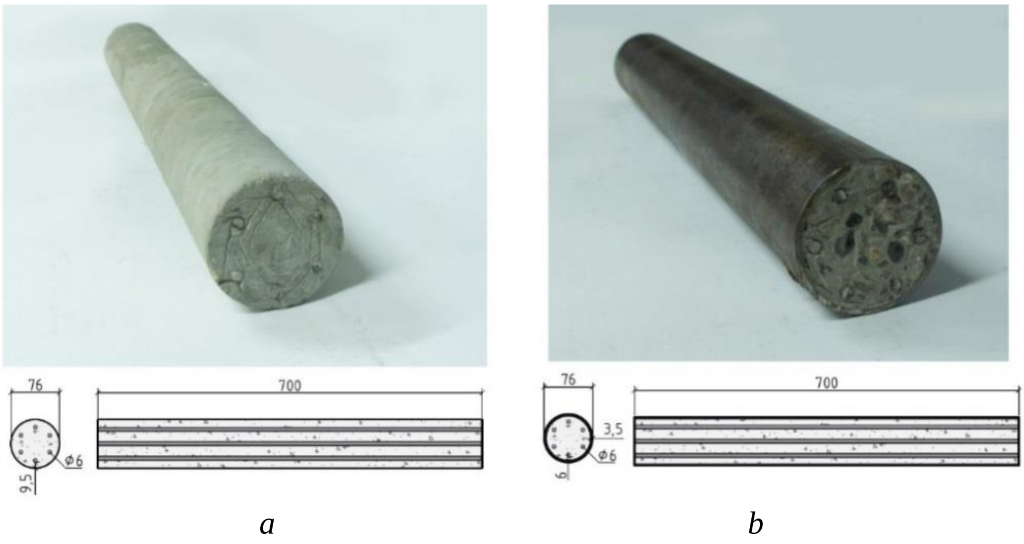


Fig. 2. Additionally made specimens: *a* – reinforced concrete (700 mm); *b* – reinforced concrete-filled steel tube (700 mm)

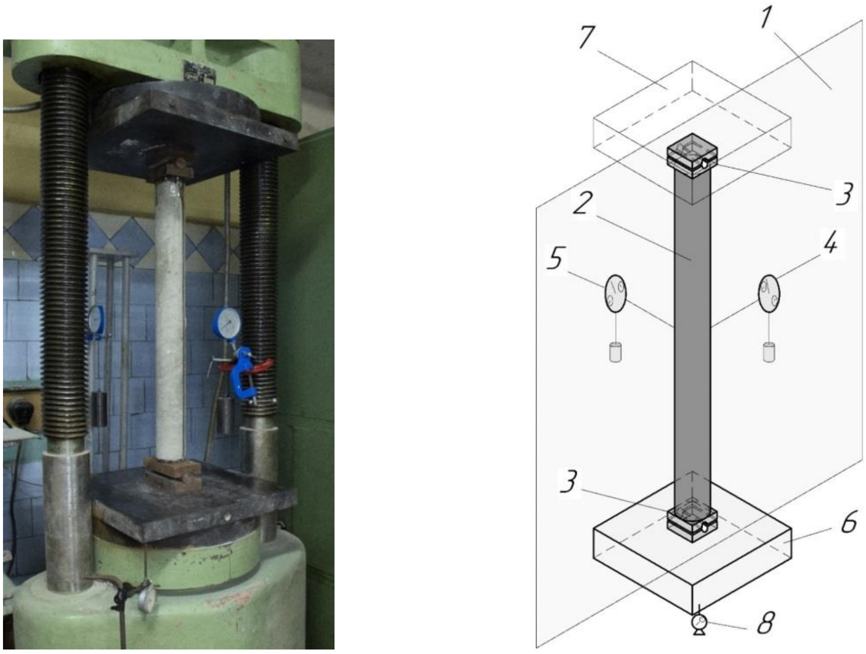
Testing operations were carried out in two stages:

– at the first stage, specimens 100 mm long were tested (fig. 3) [1]. The testing operations were carried out using a P-125 press (maximum force – 250 kN) until destruction and complete loss of bearing capacity. In this case, the breaking load was fixed;

a *b*

Fig. 3. Testing specimens 100 mm long: *a* – general view; *b* – schematic diagram of the experimental setup: *1* – tested specimen; *2* –movable loading plate; *3* – fixed loading plate

– at the second stage, specimens 700 mm long were tested (fig. 4). To build characteristic diagrams, additional equipment was installed (fig. 4*b*) – deflection meters in and out of the buckling plane, as well as an indicator that fixes the convergence of the plates.



a *b*

Fig. 4. Testing operations of specimens 700 mm long: *a* – general view; *b* – schematic diagram of the experimental setup: *1* – buckling plane; *2* – tested specimen; *3* – cylindrical support hinge; *4* – deflection meter in the plane of buckling; *5* – deflection meter from the buckling plane; *6* – movable loading plate; *7* – fixed loading plate; *8* – indicator for registering the convergence of plates

Besides, testing operations were carried out on a concrete specimen 300 mm long to plot the material deformation diagram. To fix longitudinal deformations, strain gauges were installed on the sample. During the testing operations, the position of the specimen was corrected in order to eliminate random eccentricities. Fig. 5 shows a view of the test setup.

Fig. 5. Installation for tensometric testing of concrete

The testing operations were carried out in the laboratory of the Department of Building Structures of NNGASU. The load was applied smoothly with video recording of instrument readings, which made it possible to record readings with a high degree of accuracy. In accordance with the requirement of GOST 28570-2019, before testing, the ends of the specimens were leveled by applying a layer of compo based on an epoxy composition.

Experimental results. The following criteria were introduced to evaluate the results of the research:

1. The load at which there was a complete loss of bearing capacity.
2. The nature of the loss of bearing capacity.
3. The nature of the destruction.

When testing the first sample of concrete in the form of a cylinder, the maximum load value was set, 49 kN, the nature of the loss of bearing capacity is represented as a loss of strength, and the nature of the destruction is brittle destruction.

When testing the second sample of reinforced concrete in the form of a cylinder, the maximum load value of 58 kN was established, the nature of the loss of bearing capacity is represented as a loss of strength, and the nature of the destruction is brittle destruction.

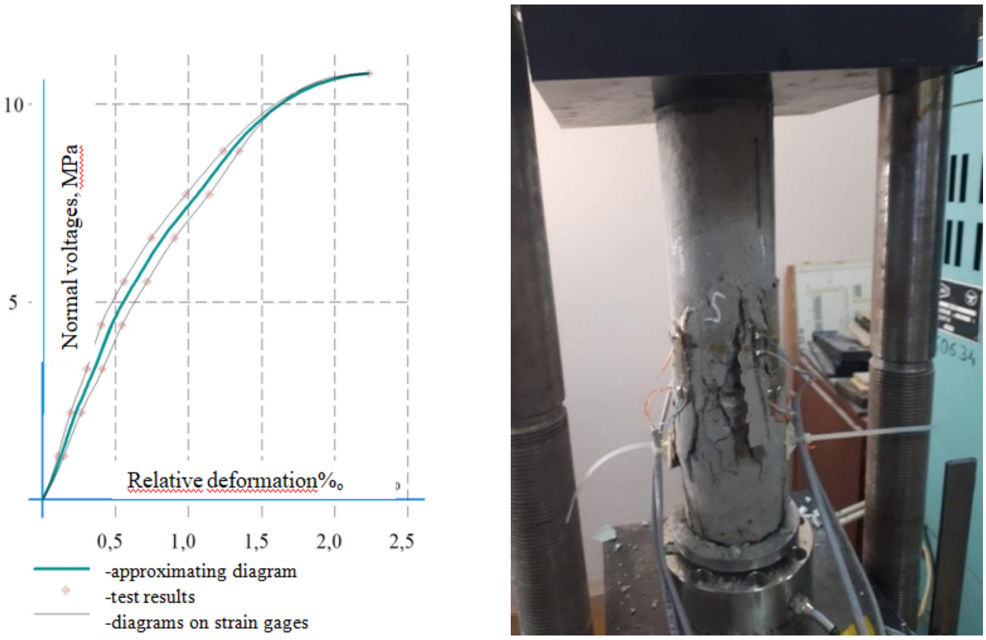
When testing the third sample of concrete in the form of a cylinder in a cylindrical metal shell, the maximum load value, 498 kN, was established, the nature of the loss of bearing capacity is represented as a transition to a plastic state, and the nature of destruction is plastic deformation followed by an explosion.

When testing the fourth sample ofreinforced concrete in the form of a cylinder in a cylindrical metal shell, the maximum load value, 612 kN, was established, the nature of the loss of bearing capacity is represented as a transition to a plastic state, and the nature of destruction is plastic deformation followed by an explosion.

When testing the fifth sample of concrete in the form of an oblong cylinder (700 mm), the maximum load value of 59 kN was established, the nature of the loss of bearing capacity is represented as a loss of strength, and the nature of destruction is brittle destruction.

When testing the sixth sample of reinforced concrete in the form of an oblong cylinder in a metal shell (700mm), the maximum load value was set, 390 kN, the nature of the loss of bearing capacity is represented as a transition to a plastic state and buckling, according to the test results, the sample did not collapse.

Fig. 6 shows the deformation diagram of a concrete specimen, as well as its appearance after destruction. Fig. 7 shows diagrams obtained from indicators (fig. 4) for reinforced concrete and concrete-filled steel tube samples 700 mm long.



а　　　　*б*

Fig. 6. Results of tensometric tests of a concrete specimen: *a* – strain diagram; *b* – specimen after destruction

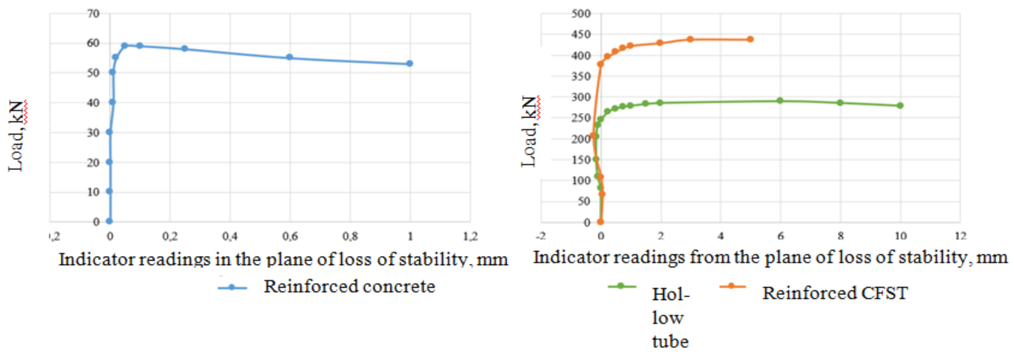


Fig. 7. Diagrams from indicators in the buckling plane (red) and from the buckling plane (green) for specimens 1 (reinforced concrete) and 2 (reinforced concrete-filled steel tube) 700 mm long

Conclusions. The following conclusions based on the conducted research can be drawn.

1. The maximum load of a concrete specimen 300 mm long was 45 kN, which is somewhat lower than the breaking load of a concrete sample 100 mm long. First of all, this is due to the influence of transverse compression in the area of the stops when testing a short specimen, which leads to a slight increase in the bearing capacity.
2. Reinforced concrete specimens 100 mm and 700 mm long demonstrated the same bearing capacity. Analysis of the bearing capacity showed that the destruction occurred primarily as a result of the loss of stability of the samples reinforcement. This is confirmed by their appearance after destruction (Table 1). This is indirectly justified by the fact that the total load that 6 rods made of A500 reinforcement can withstand is 57.7 kN [16], which practically corresponds to the final breaking load of the samples.
3. The adoption of a steel tube-clip increased the bearing capacity of concrete by 449 kN, while the bearing capacity of a tube 76×3.5 mm grade 09G2S is 313 kN [16]. Therefore, the contribution to the increase in bearing capacity increases by 43 %. This is explained, on the one hand, by the fact that the concrete core prevents the loss of stability of the tube wall, and the tube, in turn, prevents the transverse deformation of the concrete and its subsequent spalling. Thus, the total bearing capacity exceeds the algebraic sum of the bearing capacities that make up the system.
4. The adoption of reinforcement into concrete-filled steel tube specimen increases the bearing capacity by 114 kN, while the bearing capacity of the reinforcement is 57.7 kN. Therefore, its contribution to the bearing capacity of the concrete-filled steel tube element due to the constraint of the section increases by 98%.
5. The bearing capacity of a 700 mm long reinforcedconcrete-filled steel tube sample was 390 kN, which is 60% of the bearing capacity of a 100 mm long specimen. Despite the decrease in the bearing capacity due to the buckling process, the contribution of the adoption of the steel cover tube is 331 kN. At the same time, the bearing capacity of a tube 700 mm long made of 09G2S steel is 291 kN, thus the contribution to the bearing capacity increases by 14 %. At the same time, the plastic nature of the fracture is important, in contrast to the brittle fracture of reinforced concrete and the instantaneous buckling of the steel tube.

Research has substantiated the effectiveness of the use of composite concrete-filled steel tube elements and a nonlinear increase in the bearing capacity while ensuring the compatibility of materials.

The work was carried out within the state assignment to IAP RAS for fundamental scientific research for 2024-2026 (topic FFUF -2024-0031, No 1023032800130-3-2.3.2).

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УДК [691.3 +669.14]: 621.643

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ПРОЧНОСТЬ И УСТОЙЧИВОСТЬ МОДЕЛЕЙ ТРУБОБЕТОННЫХ И ЖЕЛЕЗОБЕТОННЫХ КОЛОНН

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Ключевые слова: трубобетон, композиционные материалы, разрушение, потеря устойчивости, трехосное сжатие бетона.

Приводится обобщение результатов, ранее полученных и опубликованных авторами в различных изданиях. Анализируется общая нормативная методика расчета железобетонных и трубобетонных конструкций, обосновывается необходимость проведения модельных и натурных экспериментов, описывающих деформирование, разрушение и потерю устойчивости сжатых трубобетонных конструкций. Выявлено наличие взаимного усиления составляющих системы, что приводит к нелинейному приросту несущей способности и характерно для композитных материалов, активно применяющихся в различных технических системах.

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Получено: 22.01.2024 г.