Strength and deformation property enhancement of compressed steel tube-concrete elements using super concrete and thin-shell structure

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Abstract. The article analyzes the changes in the strength and deformation property of compressed steel tube-concrete elements when the quality indicators of the original concrete (strength class for axial compression) and the metal shell are changed. The methodology of testing for central compression of steel tube– concrete columns with a core of ordinary and super concrete with a thin-shell structure is described. Comparative dependences of the relative deformations in the axial and circumferential directions depending on the relative loading levels, destructive load values for samples from ordinary and super concrete are presented. According to the results of the research, it was determined that with an increase in the class of concrete, the efficiency ratio of the concrete is reduced by an average of 12%, however, the increase in bearing capacity remains quite noticeable. In addition, the use of high-strength concrete class C80 increases the deformability by about 10% compared with concrete class C40 steel-concrete columns, with significant savings in metal.

1. Introduction
For high-rise buildings filled with a large number of technological equipment, the use of tube-concrete columns as bearing structures is especially important [1-17]. With a high bearing capacity, these structures are quite compact, and the advantageous combination of super concrete and steel shell in operation allows one to significantly reduce steel consumption, thereby reducing the cost of construction object.

In the laboratory of reinforced concrete structures at FSBEI HE "NMSTU" were started up and carried out experimental studies to determine the bearing capacity and deformability of steel tube-concrete columns of a high-rise structure with a core of super concrete and thin-shell structure.

2. Methodology
Modeling theory methods [18], steel tube-concrete three-meter columns of the designed high-rise construction of an energy storage device with a height of 300 meters and dimensions in the plan of 300x300 meters, with a shell of a non-standard tube ∅365x5mm, were modeled with a shell of ∅ 112x1.5mm. At the same time, both in real columns and in models, super, straining, self-stressing concrete was used, the initial ingredients for the manufacture of which were the following materials:

- Portland cement of Magnitogorsk cement plant brand M500-D0;
- Cube-shaped crushed stone from Gumbeiskii granite quarry of a fraction of 5-20 mm of mark M1400;
- Sand washed from Naravchatsky sand pit of the 0-5 mm fraction;
- Concrete modifier Embelit 0-100;
- Sika ViscoCrete-5-600;
- Tap water according to GOST R 51232-98 of temperature 20-22 °C.

The experiment planning method selected the composition of super self-stressing concrete: the C80 concrete class was provided, the Sp1.0 self-stressing grade was provided, the self-compacting concrete mixture was monitored (the cone bleed at least P5, the mobility of the concrete mix was not less than P5).

An electro welded longitudinal hot-dip galvanized pipe \( \varnothing 112 \times 1.5 \text{mm} \), manufactured by the People's Republic of China, was used as the shell. In order to determine the strength characteristics of steel tubes in the circumferential and axial directions, tensile specimens with a width of 10 mm and strips of 400x20x1.5 mm were tested for tension, respectively.

Tensile tests showed that the average value of the yield strength of steel is: 260 MPa in the circumferential direction, 264.7 MPa in the axial direction.

It was made 2 series of prototypes. In each series there were 3 identical samples. In the first series of samples, concrete class C80 was used as a concrete core, in the second series C40.

In order to determine the physico mechanical characteristics of the initial concrete during molding, for each series of samples, control samples of concrete were made in the form of cubes with dimensions of 100 × 100 × 100 mm and prisms with dimensions of 100 × 100 × 400 mm.

Before testing, samples were stored under the same conditions at a temperature of 20 ± 30 °C.

Testing of control samples was carried out on a 200-ton hydraulic press PG-200 with an electronic measurement system. Tube-concrete samples \( \varnothing 112 \times 1100 \text{mm} \) were tested on a 500-ton hydraulic press 2PG-500 according to [19, 20].

The determination of the absolute and relative values of the shell deformation was carried out by a complex method: strain gauge with duplication of mercer clock gauges with a division value of 0.001 mm (MCG).

3. Research results

The main results of testing experimental samples, the strength characteristics of the starting materials are presented in Table 1.

**Table 1. The main results of testing experimental samples and the strength characteristics of the starting materials.**

| Series, sample | Outside diameter, \( d \), \( \text{mm} \) | Wall thickness, \( \delta \), \( \text{mm} \) | \( R \), MPa | \( R_{\text{bu}} \), MPa | \( \sigma_{\text{y}} \), MPa | \( \sigma_{\text{yz}} \), MPa | \( N_{\text{u,exp}} \), kN | \( N_{\text{u,exp}} / N_{\text{bs}} \) |
|----------------|---------------------------------|---------------------------------|-------------|----------------|----------------|----------------|----------------|----------------|
| C.112.1-1      | 112                             | 1,5                             | 93,3        | 83,3           | 260,0          | 262,7          | 1060           | 1,17           |
| C.112.1-2      | 112                             | 1,5                             | 53,2        | 42,4           | 260,0          | 262,7          | 664            | 1,26           |
| C.112.1-3      | 112                             | 1,5                             | 93,3        | 83,3           | 260,0          | 262,7          | 724            | 1,37           |
| C.112.2-2      | 112                             | 1,5                             | 93,3        | 83,3           | 260,0          | 262,7          | 708            | 1,34           |
| C.112.2-3      | 112                             | 1,5                             | 53,2        | 42,4           | 260,0          | 262,7          | 1120           | 1,21           |
A general view of the sample prepared for testing is shown in Figure 1. The general view of the samples after testing is presented in Figure 2.
Figure 2. Samples after central compression test.

Figure 3, 4 show the comparative diagrams "N-ε" for samples of series C.112.1 and C.112.2.
Figure 3. The averaged relative axial deformations $sz \times 10^{-5}$ (right) and circumferential $s\Theta \times 10^{-5}$ (left) steel shell of series No. 1 specimens.

Figure 4. Averaged relative axial deformations $\varepsilon_{sz} \times 10^{-5}$ (right) and circumferential $\varepsilon_{s\Theta} \times 10^{-5}$ (left) of steel shells of series No. 2 specimens.

For a quantitative performance assessment of steel tube-concrete elements under load, the ratio is calculated $N_{exp}/N_{bu}$ is the ratio of the maximum load that the sample withstood to the total load-bearing capacity of the concrete core and the outer tube, tested separately.

4. Conclusions
Analyzing the results we can conclude that with an increase in the class of concrete, the efficiency ratio of the concrete is somewhat reduced, however, while the growth of bearing capacity remains quite noticeable. In addition, the use of high-strength concrete class $C_{80}$ slightly increases the deformability (by about 10%) compared with concrete class $C_{40}$ steel-concrete columns with significant savings in metal.

In the future, it is planned to investigate the work of steel tube-concrete elements with a core of super concrete and thin-shell structure of stronger steel. It is expected that the use of a stronger steel shell will allow both to increase the efficiency coefficient the concrete, and to increase the carrying capacity.
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