Compressed tube-concrete elements with the high-strength compression core and with fibreglass shell

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Abstract. The aim of the work was to assess the strength and deformability of compressed concrete elements with a core of high-strength self-stressing concrete, with strength grade of concrete C80 and fibreglass shell. The concrete core was carried out both with spiral reinforcement of the concrete core and without it. The methodology for testing two series of samples of compressed tube-concrete elements for central compression is described. Comparative data on the breaking load of both series of samples, as well as graphs of relative deformations in the axial and circumferential directions depending on the relative loading levels are presented. It was experimentally established that the presence of spiral reinforcement for 1.8% increased the strength of compressed concrete elements by 9% and increased the effect of the hooping by 11%. The limiting axial deformations increased about 1.5 times. Thus, the device of the spiral reinforcement of the concrete core is one of the rational ways to increase the operation efficiency of compressed concrete elements with fibreglass shell.

1. Introduction
Despite the indisputable advantages of compressed concrete filled steel tube elements (CCSTE), such as load-carrying ability, increased fire resistance compared to metal structures, high reliability of their operation, manufacturability and relative efficiency [1-3], they are rarely used in corrosive medium, since all disadvantages of metal structures are inherent external shell, and, first of all, low corrosion behaviour.

There are known examples of CCSTE use as a supporting module of transport structures: decking supports across watercourse [3-5]. However, in this case, CCSTE with a metal shell lose economic advantages, because for the entire period of their operation it is necessary to provide corrosion protection (to increase the chemical resistance of structural materials, to isolate the metal surface from the corrosive medium, and other methods).

To date, polymeric composite materials (PCM) are widely used abroad (the USA, China, Japan, Germany, Great Britain, etc.): fibreglass, carbon fibre, basalt plastic, aramidoplastic. These materials have several advantages compared with steel: relatively high strength, high corrosion resistance, high chemical resistance, resistance to seasonal and daily temperature changes, and no corrosion of connecting elements, low specific gravity, and low working expenditures.
Due to the given advantages CSTE with PCM shells are being investigated in the USA and Canada [6-20]. In Russia the PCM production is also gathering speed in connection with the adopted program for the composite materials introduction, structures and products from them in the building complex of the Russian Federation (approved by order of the RF Regional Development Ministry of July 24, 2013 No. 306). However, the regulatory framework for their use is poorly developed. This circumstance inhibits the use of PCM in the construction industry. Therefore, research in the field of CCSTE using PCM is rather relevant.

2. Methodology

In order to achieve this goal, the specialists of the reinforced concrete structure laboratory of FSBEI HE “NMSTU” manufactured and tested 2 series of CCSTE samples for short-term central compression. CCSTE sample was a fibreglass tube-shell with the height of 500 mm and 112x6 mm, filled with high-strength, tensile, self-stressing concrete, the initial ingredients for the manufacture of which were the following materials:

- Portland cement of brand M500-D0 of Magnitogorsk cement plant;
- cube-like crushed stone from Gumbeisk granite quarry of a fraction of 5-20 mm of brand М1400;
- sand washed from Naravchatsky sand pit of the 0-5 mm fraction;
- concrete modifier Embelit 0-100;
- Sika plasticizer ViscoCrete 5-600 SP;
- tap water according to GOST R 51232-98 of temperature 20-22 ºС.

The class of concrete not lower than B80, the self-tensioning brand Sp1.0 were provided by design of mixture of high-strength self-stressing concrete, self-compacting of the concrete mix was monitored (the spread of the cone corresponds to a grade of at least R5, the mobility of the concrete mix is not less than P5).

Series 1 differed from series 2 by the presence of confinement reinforcement in the form of a spiral made of reinforcing wire of class Bp500 with a pitch of 25 mm. The coefficient of spiral reinforcement was 1.8%. Confinement reinforcement prior to concreting was installed in a fibreglass tube-shell.

The produced spiral is shown in Figure 1.

A fiberglass tube-shell with the installed spiral is shown in Figure 2.
In order to determine the physic mechanical characteristics of the initial concrete, for each series of samples, control samples were made of concrete 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 the temperature of 20 ± 30 ° C. Testing of control samples was carried out on a 500-ton hydraulic press PG-500 according to [15]. Determination of shell deformations was carried out using a complex method: the strain gauge method with duplication of measurements with hour-type indicators with a division value of 0.001 mm by mercer clock gauge (MCG).

3. Results
The main results of testing experimental samples CCSTЕ, the strength characteristics of the initial materials are presented in Table 1.

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

| Series, sample | Outer spiral diameter d mm | The diameter of the spiral wire, mm | Prism strength of concrete \( R_{hu} \), MPa | Limit tube strength in district direction \( \sigma_{u \theta} \), MPa | Module elasticity rotationally \( E_\theta \), GPa | \( N_{u \text{exp}} \), kN | \( N_{u \text{exp}} / N_{bs} \) |
|---------------|---------------------------|-----------------------------------|---------------------------------|-----------------|-----------------|----------------|------------------|
| C.1-1         |                           |                                   | 84,3                            | 236,7           | 22,49           | 1700,9         | 1,49             |
| C.1-2         |                           |                                   | 84,3                            | 236,7           | 22,49           | 1767,6         | 1,55             |
| C.1-3         |                           |                                   | 79,4                            | 236,7           | 22,49           | 1720,9         | 1,51             |
| C.2-1         | 90                        | 5,0                               | 79,4                            | 236,7           | 22,49           | 1901,0         | 1,68             |
| C.2-2         |                           |                                   | 84,3                            | 236,7           | 22,49           | 1867,6         | 1,65             |
| C.2-3         |                           |                                   | 84,3                            | 236,7           | 22,49           | 1887,6         | 1,70             |

In order to quantify the performance of CCSTЕ with a fibreglass shell under load, we calculated the coefficient of the hooping \( m = N_{u \text{exp}} / N_{bs} \) - the ratio of the maximum load that the sample withstood to the total strength of the concrete and the outer tube tested under unconfined compression.

The diagram of the mechanical devices on the experimental samples is presented in Figure 3.
Analysis of the data in Table 1 indicates a noticeably greater hooping effect in samples with spiral reinforcement. The average value of the coefficient $m$ for samples of the C.2 series was 1.68, which is 11% higher compared to the samples of the C.1 series. The absolute strength value of the specimens with spiral reinforcement was 9% higher, despite the slightly lower strength of the original concrete. Thus, a noticeable positive effect of spiral reinforcement was experimentally revealed on the strength of concrete samples in a fibreglass shell.

Even more, the presence of spiral reinforcement affected the deformability of CSTE prototypes. The relative axial deformations of specimens of the C.2 series reached 1.2%, which is about 1.5 times greater than the specimens of the C.1 series.

The destruction nature of the samples of both series was fragile. After the beginning of the shear of the concrete core and a slight buckling of the outer shell, its rupture was observed (Figure 4).
4. Conclusions
Analysing the obtained results, we can conclude that the presence of spiral reinforcement with a confinement reinforcement ratio of 1.8% increased by 9% the strength of CSTE samples and increased the effect of the hooping by 11%. At the same time, the limiting axial deformations increased by 1.5 times. Thus, the device of confinement reinforcement of the concrete core is one of the rational ways to increase the operation efficiency of compressed concrete elements with fibreglass shell.

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