Research of Concrete Durability in Compressed Elements with Different Types of Confinement Reinforcements

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Abstract. The paper presents experimental research of short center compressed elements with circular cross section in different types of concrete confinement reinforcements, namely by introducing glass fiber-reinforced shell, steel spiral and by using these two types together was conducted. The results of the conducted experiments show the positive influence of both outer glass fiber-reinforced shell and spiral reinforcements on the durability of such elements. The highest degree of durability was achieved when two types of confinement reinforcements were used simultaneously. The durability of the concrete core of the samples made from class C40 concrete increased by 3.25 times and equaled 135 MPa. In case of the initial class C80 concrete the effect of confinement reinforcements was considerably smaller but nevertheless it was high enough. The durability of the concrete core increased by 2 times. The introduction of two types of confinement reinforcements considerably improved the deformability of compressed elements. The maximum recorded values of contraction longitudinal strain of the samples made of high endurance concrete were about 1%, and in case of concrete class C40 they were 2.4%. Such high level of deformability in compressed elements will help to effectively use high durability longitudinal reinforcements with the compression yield strength up to 2000 MPa and higher in them.

1. Introduction

Over the last years compressed elements made of concrete in concrete filled glass fiber-reinforced tube (CFGFRT) have become very commonly used in construction [1-9]. The increased interest in them is generated due to the considerable economy of labour and non-human resources in actual use. In compressed CFGFRT elements the outer shell is simultaneously the stay-in-place formwork and the longitudinal and confinement reinforcements. Confinement reinforcements in sufficient amount can significantly increase the durability and deformability. Due to these qualities these constructions are highly effective.

Wider use of CFGFRT elements is limited due to the relatively high cost of glass fiber-reinforced tubes. Today the most feasible way to use them is in constructions that require increased corrosion durability qualities. For example, these can be pile foundations, various shore facilities at the sea shore, bridge pylons, etc.
In order to lower the cost of CFGFRT elements, the size of the outer glass fiber-reinforced shell (thickness of the wall and the diameter of the tube) must be reduced while keeping the necessary load-bearing capacity by using high-durability concrete and (or) additional reinforcement of the concrete core. The analysis of possible variants of the concrete core reinforcement shows that spiral reinforcements prove to be the most effective [10-12].

The purpose of this research is to compare the durability of compressed short CFGFRT elements made of concrete of different durability and various types of confinement reinforcements.

2. Methods and results of the experimental research

The experiments tested the durability of short centre compressed lab samples with circular cross section. The ratio between the length of the samples and their diameter was 4.5 series of test elements were made and tested. Each series consisted of 3 sample twins. The tested samples had the following parameters.

The CT series samples were made of concrete with the outer shell that consisted of a glass fiber-reinforced tube with the diameter of 113 mm and the wall thickness of 6.1 mm.

CR series was represented by reinforced concrete elements with the diameter of the cross section of 100 mm. The test samples of this series had confinement reinforcements in the form of a spiral. Wire Ø5 Bp500 was used as the spiral reinforcements of the frame that was wound with a 30 mm spacing around four longitudinal rods Ø6 A500C. The diameter of the spiral was 90 mm. The compressional yield strength of the reinforcement wire was $\sigma_{ys} = 548$ MPa, and that of the rod reinforcements was $\sigma_{ys} = 552$ MPa.

The CRT series samples were made of concrete in a glass fiber-reinforced tube with the diameter of 113 mm and the wall thickness of 6.1 mm. This said, the concrete core had reinforcements similar to the samples of the CR series. The concrete with compression durability class C40 was used in all the three series.

The samples in the other two series was made of concrete class C80. The HCT series samples, except for the concrete, are the exact copy of the CT series constructions, and the HCRT series samples were similar to the construction of the relative CRT series.

A glass fiber-reinforced tube used as the outer shell had the following characteristics:
- elasticity model in case of axial compression $E_{pc} = 10200$ MPa;
- elasticity model in case of circular stretching $E_{pt} = 29500$ MPa;
- durability in case of axial stretching $f_{lp} = 265$ MPa;
- durability in case of circular stretching $f_{op} = 303$ MPa;
- poisson ratio $\nu_p = 0.21$;
- specific weight $\gamma_p = 18.5$ kN/m$^3$.

In order to get more objective data when comparing durability of the samples of the tested constructions made of concrete mix of one batch, the samples of different series that had the relevant class of concrete, were made simultaneously.

After the manufacturing all the tested samples were kept at the temperature of about 20 °C during 28 days. The tests were conducted using a 500-ton hydraulic press by applying short-term compression pressure. It was applied to the whole cross-section of the constructions. The standard method specified in GOST 8829 was used.

3. Results of the experimental research

The main results of the experiments are represented in Table 1. Besides the durability of the initial concrete $f_c$ and collapse load $N_u^{exp}$, the durability of the volumetrically compressed concrete core $f_{cc}$, the coefficient of the concrete durability increase $\alpha_c = f_{cc}/f_c$ and threshold contraction axial deformation of the tested samples $\varepsilon_u^{exp}$ are represented here. The value of the volumetrically compressed concrete core durability $f_{cc}$ was calculated using the following formula
where $N_f$ and $A_f$ are the threshold compressing force in the rods of the longitudinal reinforcements and the area of their cross-section (they are taken into account if there is a spiral frame); $A$ is the area of the cross-section of the test sample.

Table 1. Main Test Results for Laboratory Specimens

| Set, specimen | $f'_c$, [MPa] | $N_u^{\exp}$, [kN] | $f_{cc}$, [MPa] | $\alpha_c$ | $\varepsilon_u^{\exp}$, [%] |
|---------------|---------------|---------------------|-----------------|------------|-----------------|
| CT-1          | 41.8          | 990                 | 98.7            | 2.36       | 1.50            |
| CT-2          | 40.9          | 1020                | 101.7           | 2.49       | 1.55            |
| CT-3          | 42.6          | 1080                | 107.7           | 2.53       | 1.38            |
| CR-1          | 41.8          | 590                 | 68.2            | 1.63       | 0.93            |
| CR-2          | 40.9          | 590                 | 68.2            | 1.67       | 1.11            |
| CR-3          | 42.6          | 620                 | 72.0            | 1.69       | 0.82            |
| CRT-1         | 41.8          | 1410                | 135.9           | 3.25       | 2.57            |
| CRT-2         | 40.9          | 1380                | 132.8           | 3.25       | 2.22            |
| CRT-3         | 42.6          | 1440                | 138.9           | 3.26       | 2.40            |
| HCT-1         | 80.5          | 1283                | 121.1           | 1.50       | 0.67            |
| HCT-2         | 82.4          | 1300                | 122.8           | 1.49       | 0.72            |
| HCT-3         | 81.7          | 1300                | 122.8           | 1.50       | 0.77            |
| HCRT-1        | 80.5          | 1653                | 160.4           | 1.99       | 1.18            |
| HCRT-2        | 82.4          | 1693                | 164.4           | 2.00       | 0.82            |
| HCRT-3        | 81.7          | 1733                | 168.4           | 2.06       | 0.90            |

The analysis of the results shows that the type of confinement reinforcements influenced the durability of the concrete core and the tested samples the most. Thus, with class C40 concrete if only spiral reinforcements were used, the concrete durability increased on average by 1.66 times, the glass fiber-reinforced shell increased it by 2.46 times and when both types of confinement reinforcements were used, it rose by 3.25 times. The CRT series samples proved to be stronger than CT series samples by about 35%. The same rise in durability was achieved by using spiral reinforcements of the samples made of high-durability concrete in a glass fiber-reinforced shell.

The comparison of the CRT and HCRT series samples as well as these of the CT and HCT series shows that when the durability of the initial concrete increased by two times, the durability of the samples rose slower, by 20% and 26% correspondingly. This is explained by the fact that high-durability concrete samples in their limit state with the same confinement reinforcements as the regular durability concrete have a lower value of relative side pressure $\sigma_{cr}/f'_c$. According to the published research data [13], the value of relative side pressure influences directly the rise in the durability of volumetrically compressed concrete.

Maximum recorded values of longitudinal deformations $\varepsilon_u^{\exp}$ of the tested samples essentially depended on the intensity of the confinement reinforcements and the class of the initial concrete. Minimum values of those deformations were recorded in the samples made of high-durability concrete of HCT series. Their value on average was 0.72% that is three times higher than in similar deformations of monoaxially compressed concrete. Deformability of similar samples made of class C40 concrete was significantly higher. For instance, the values of deformations $\varepsilon_u^{\exp}$ in CT series samples on average reached 1.48%. The highest deformability was delivered by the CRT series samples in glass fiber-reinforced shell with spiral reinforcements of concrete. Their average value $\varepsilon_u^{\exp}$ was 2.4%. High
level of deformability of compressed elements helps to effectively use high-durability longitudinal reinforcements in them.

The characteristics of the damage of tested samples were different. Reinforced concrete elements with spiral reinforcements showed almost complete destruction of the protective layer (Figure 1,a) before the load limit was reached. When the load was further increased, the concrete core was smashed inside the spiral.

The destruction of CT and HCT series samples was fragile. Initially, (right after the outer shell bulged) parts of the concrete core were moved. After that the shell was breached (Figure 1,b). Spiral reinforcements in CRT and HCRT series samples slightly changed the characteristics of the destruction by making it more flexible. However, visually it looked the same as in the CT and HCT series samples.

![Figure 1. Fracture pattern of samples of series CR (a) and CT (b)](image)

4. Conclusions

The results of the conducted experiments show the positive influence of outer glass fiber-reinforced shell and spiral reinforcements on the durability of short compressed CFGFRT elements. High load performance of such samples can be explained by the significant durability of the concrete that has two types of confinement reinforcements at the same time. Thanks to those reinforcements the durability of the concrete core of the samples made from class C40 concrete increased by 3.25 times and equaled 135 MPa. In case of the initial class C80 concrete the effect of confinement reinforcements was considerably smaller but nevertheless it was high enough. The durability of the concrete core increased by 2 times.

What is more, the introduction of two types of confinement reinforcements considerably improved the deformability of compressed elements. The maximum recorded values of contraction longitudinal strain of the samples made of high endurance concrete were about 1%, and in case of class C40 concrete they were 2.4%. Such high level of deformability in compressed elements will help to effectively use high durability longitudinal reinforcements with the compression yield strength up to 2000 MPa and higher in them. The relative tests are scheduled in the foreseeable future.

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