Influence of long-term compressive stresses on strength of concrete and steel-fiber concrete prismatic element

Stepan Neutov¹, Maryna Sydorchuk¹, and Oleksii Shyliaiev¹,*

¹Odessa State Academy of Civil Engineering and Architecture, Didrikson str., 4, Odessa, 65029, Ukraine

Abstract. The strength and deformation characteristics of concrete and steel-fiber concrete on prisms and cubes are determined. Short-term and long-term tests of the samples were carried out taking into account the recommendations of the regulatory documents for the testing of concrete. Loading of samples with a long load was carried out in force installations (stands) consisting of four metal rods to which rigid loading plates were fixed at certain levels with threaded connections. To cover the entire operational spectrum of the stress state of real reinforced concrete elements, levels of 0.3; 0.4; 0.5; 0.67 and 0.8 from the short-term destructive load were adopted as long-term loading levels. All samples, which were more than a year under the action of a long-acting load, increased their bearing capacity. Prisms from steel-fiber concrete, which were under the influence of a long-acting load during 370 days, increased the bearing capacity, depending on the level of load, by 30-50%. The higher load level, the higher the creep rupture strength. When the loading was repeated before the destruction, the deformations of steel-fiber-concrete prisms changed linearly.

1 Introduction

Among materials used in construction, concrete and reinforced concrete are the most common ones. According to some reports, the production of concrete per year is one ton per inhabitant of our planet. Increasing use in construction is found in high-strength powdered concrete obtained by the use of modern modifiers and finely dispersed mineral aggregates. However, along with obvious advantages, they have a significant disadvantage compared with traditional concrete - brittleness. This is one of the reasons limiting the wide use of high-strength powdered concrete in construction. An effective solution of this problem is the addition of steel fiber to the concrete matrix. Thus, a spatial framework was created that increases the resistance to cracking and the fracture toughness of concrete, frost resistance, tensile strength, bending strength, torsion strength, etc. [1-4]. Despite the fact that, both in our country and abroad, studies of steel-fiber-concrete are conducted quite a

*Corresponding author: shyliaiev@gmail.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).
long time, information on the physicomechanical and rheological properties of steel-fiber concrete is relatively small, and the available data vary in a considerable interval.

For solving multiple problems in the design of concrete and reinforced concrete structures, it is very important to take into account the long processes taking place in concrete [5-8], since practically all structures in real conditions are loaded with long-term loads [9]. In determining the strength, rigidity and crack resistance it is necessary to know the parameters characterizing the long processes occurring in concrete, which correspond to the concrete types and compositions of the used concrete [10].

2 Results

In our studies, the strength and deformation characteristics of concrete and steel-fiber concrete were determined on concrete prisms with dimensions 100 × 100 × 400 mm and cubes with dimensions 100 × 100 × 100 mm. Depending on the tasks to be performed during the experiments, the twin samples were combined into groups and series. Samples of each group were made in one step. Prisms and cubes were concreted in metal cassette formwork. The concrete mixture was made in a free-fall concrete mixer. Before laying in the formwork, the mixture for further homogeneity was additionally mixed by hand. Concrete consolidation in the formwork was carried out on a laboratory vibration table. Before the beginning of the experimental studies, the samples were stored at a temperature of 18-24°C. Before the test, the attachments for the installation of dial indicators were fastened to the side edges of the prism.

The method of short-term and long-term testing of samples was made taking into account the recommendations of the regulatory documents for the testing of concrete [11].

The physical and mechanical characteristics of concrete and steel-fiber concrete elements under short-term loading were determined on a universal hydraulic press (500 kN).

Determination of the modulus of elasticity and prismatic strength was preceded by the alignment of the samples along the physical center by applying test loads, causing a stress of up to 0.2 from the prismatic strength. The centering was performed to ensure that the deformations along the four faces of the sample were approximately the same and almost completely reversible. The loading was carried out in steps of 0.1 from the prismatic strength. Deformations were measured at each loading stage. Maximum force, perceived by the sample before destruction, was taken as the magnitude of the destructive load.

Loading of the samples with a long-term load was carried out in force installations (stands) consisting of 4 metal rods with a diameter of 46 mm, to which rigid loading plates (4 pcs) were attached to certain levels using threaded connections (Fig. 1). To maintain the load during long-term tests at a given level, the transfer of forces from the hydraulic jack to the prisms studied was carried out through a force installation consisting of 4 springs and 2 load plates. The strength of each spring is 100 kN.

All forces generated by the force device, are balanced within the upper and lower loading plates. From the installation on the foundation, only its own weight and possible dynamic impact during the fragile destruction of the prisms are transmitted.

Before loading, each spring cassette was calibrated using a standard dynamometer (500 kN), located at the location of the experimental sample. The load during the experiment was maintained at the required level and controlled by the deformations of the spring unit and the pressure gauge of the pumping station.
The height of the installation in one power line, i.e. in two floors, there were two samples: one of ordinary concrete, and the second - from the steel-fiber concrete. Thus, during the entire experiment (370 days), the mode and load level for both samples were exactly the same.

To determine the bearing capacity, as well as to compare the results of short-term and long-term loading, in each group of samples, three prisms were brought to destruction by a short-time load on the hydraulic press. Five prisms of each composition of concrete were loaded with a long-term load in force stands and four prisms of each group were stored until the end of the experiment to determine the corresponding prism strength. As a result of short-term tests it was established that the prismatic strength of ordinary concrete is 235 kN, and that of steel-fiber concrete is 252 kN.

To cover the entire operational spectrum of the stress state of real reinforced concrete elements, levels of 0.3; 0.4; 0.5; 0.67 and 0.8 from the short-term destructive load were adopted as long-term loading levels. Fig. 2 shows the results of long-term tests for three levels - 0.3; 0.5 and 0.8. The solid lines show the deformation of concrete, and the dashed lines show the steel-fiber concrete. Creep deformations of steel-fiber reinforced concrete are on 20% lower than concrete in average.

From the results presented in Fig. 2, it can be seen that the deformation development under long-term loading can be conditionally divided into 3 stages. At the first stage there is an accelerated deformation. The deformations appeared during this period are almost 75% of the total deformations for the entire time of observations. At the second stage, deformation occurs at a conditionally constant rate, i.e. the increasing of deformations is practically linear. At a load level of 0.3 R, the linear part is stable after 35-40 days, for level 0.8 - after 65-70 days. The deformations appeared at this stage are 20-23% of their total
value. And, finally, at the third stage the rate of increasing of deformations practically tends to zero. The graph of the deformations is almost parallel to the horizontal axis.

Fig. 2. Results of long-term tests (creep curves).

Fig. 3 shows the results of three stages of loading of concrete prisms in force stands. At the first stage, as already noted, the prisms were loaded with a short-term load to the planned level of 0.3; 0.5 and 0.8. The deformations corresponding to this stage of loading are given in the first part of Table 1. From the obtained results it is clear that at this stage of loading the strain values are practically proportional to the level of the load, namely, at a level of 0.8 the strain is 3 times higher than at a level of 0.3, etc.

| Level | Value | Difference, % | Value | Increment to I stage | Difference, % | Value | Increment to II stage | Difference, % | Limit of deformation |
|-------|-------|---------------|-------|----------------------|---------------|-------|----------------------|---------------|---------------------|
| 0.3   | 0.25  | 100           | 0.68  | 0.43                 | 100           | 1.4   | 0.72                 | 170           | 1.4                 |
| 0.5   | 0.37  | 148           | 1.44  | 1.07                 | 149           | 2.1   | 0.66                 | 157           | 2.1                 |
| 0.8   | 0.75  | 300           | 2.48  | 1.73                 | 302           | 2.9   | 0.42                 | 100           | 2.9                 |

At the second stage, a constant load was applied to the prisms during 370 days, corresponding to the selected loading levels. In Fig. 3 this stage is represented by horizontal lines. Load is constant, concrete "creeps". The deformations corresponding to this stage of loading are presented in the second part of Table 1. Differences in deformations accumulated at this stage of loading are more significant than in the previous stage. At a level of 0.8, the strain accumulated due to the creep of concrete is 3 times higher than at a level of 0.3 R.

And, finally, at the 3rd stage, the prisms were loaded to destruction in force stands without preliminary unloading. The deformations appeared in the samples at this stage are listed in part 3 of Table 1. The obtained data indicate that the deformation pattern here is opposite to the first two stages. With repeated loading of the deformation of samples preloaded to a level of 0.3 R are 1.7 times greater than similar deformations at a level of 0.8 R. The limiting deformations accumulated in the loaded samples at the time of destruction for the entire three-stage load period are the following:
- at level 0.3 – $\varepsilon = 1.4 \times 10^3$;
- at level 0.5 – $\varepsilon = 2.1 \times 10^3$;
- at level 0.8 – $\varepsilon = 2.9 \times 10^3$.

Fig. 3. Three-stage loading of concrete prisms in force stands.

From the results presented in Fig. 3, it follows that all samples that have been more than a year under the influence of a long-acting load have increased their carrying capacity. The higher the level of the continuous load, the more compacted concrete (see ultimate deformations $\varepsilon$) and, naturally, its stress is higher. Samples loaded to the level of 0.8 $R$, in 370 days increase their bearing capacity by 40.5%. For the same time the limit stress of the sample, loaded to a level of 0.3 $R$, increased by 18.3%.

Fig. 4. The bearing capacity of steel-fiber concrete prisms previously loaded with a long-acting load.
In each stand two samples were simultaneously loaded. In the process of loading, of course, only one was destroyed, the bearing capacity of which was lower. In all three installations, where simultaneously one under the other was installed concrete and steel-fiber concrete samples, the prism from ordinary concrete was broken first. The results of the experiment are shown in Fig. 3.

The unbroken and simultaneously unloaded steel-fiber concrete prism after the destruction of the concrete sample was moved to a hydraulic press and subjected to short-term loading until failure.

The loading speed on the press was about the same as at the stand. The results of the tests are shown in Fig. 4.

3 Conclusions

From the results obtained, it can be seen that the prisms of steel-fiber concrete, which were during 370 days under the influence of a prolonged load, increased the bearing capacity, depending on the level of load, by 30-50%. The higher the load level, the higher the limiting stress. When the loading was repeated again, the deformations of the steel-fiber concrete prisms changed linearly according to a linear law (Fig. 4). This is explained by the fact that in the process of three-stage loading, fast-flowing creep of concrete was chosen.

References

1. K.V. Talantova, Arch. i stroit. Tez. dokl. konf., Tomsk, 16-17 (2002)
2. V.B. Aronchik, Study of the work of reinforcing fiber in fiber concrete (Riga, 1983)
3. S.H. Kwon, R.P. Ferron, Y. Akkaya, S.P. Shah, Int. Journ. Of Conc. Str. And Mat., 54, 205-221, (2007)
4. Y. Yuguang, J.C. Walraven, J.A. D. Uijl, Heron, 54, 205-221, (2009)
5. A.V. Sakvarelidze, Bet. I Zhelez., 8, 12-13, (1986)
6. A.V. Sakvarelidze, Bet. I Zhelez., 3, 8-9, (1987)
7. Yu.V. Puharenko, I.U. Aubakirova, V.Yu. Golubev, Tehn. Bet., 03-04, 44-45 (2010)
8. A.V. Mishina, Nauch.-tehn. Journ. “Str. I rekoncr.”, 6(38), 70-74, (2011)
9. Yu.V. Veryuzhskiy, A.B. Golyshev, V.I. Kolchunov, Reference manual for structural mechanics (ASV, Moscow, 2014)
10. D.A. Smirnov, Vestn. Grazhdan. Inzhen., 3(28), 56-60, (2010)
11. GOST 24544-81 Concretes. Methods of shrinkage and creep flow determination (1981)