Fiber reinforcement as an alternative to the compressed zone linear reinforcement and the flexible concrete elements stretched zone prestressing

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Abstract. The results of a numerical experiment in the framework of a theoretical study of the strength and crack resistance of the reinforced concrete beams available or non-available in fiber reinforcement are presented. The fiber reinforcement presence influence on the strength and crack resistance of the reinforced concrete beams’ normal sections is determined by varying the following parameters: working reinforcement class; percentage of reinforcement with steel reinforcement; the presence and degree of the reinforced zone reinforcement prestressing; the presence or absence of the beam compressed zone reinforcement; the steel fiber reinforcement presence. Reinforcement of concrete with steel fiber had a significant impact on the theoretical strength and crack resistance of the reinforced concrete elements’ normal sections, both in the presence and in the absence of the working reinforcement prestressing. The calculation showed that in some cases the presence of fiber reinforcement will eliminate the prestressing of the working reinforcement or significantly reduce its level, abandon the reinforcement in the compressed zone and, under the certain conditions, replace the high-strength prestressed reinforcement A600 with the reinforcement A400 without increasing the total consumption of steel by the sample.

Introduction
One of the main problems of the prestressed reinforced concrete flexible elements, at present, is the complexity of the creating prestressing technology, as well as the almost complete impossibility of its creation in a building site.

At the moment, in construction practice, there has been a significant increase in monolithic house-building using the concrete pumps and a practical complete refusal of the building reinforced concrete frame precast-monolithic structure. However, in some situations, it becomes necessary to use reinforcement in bent elements, for example, in cases of overlapping the large spans when it is impossible to increase the section height of an element to avoid the excess deflection and crack opening width, due to the inability of concrete to resist significant tensile stresses. However, in the monolithic structures’ manufacturing, the creation of prestressing reinforcement in a construction site can be fraught with many problems due to the complexity of its technology, and in most cases, it is simply impossible. This question is especially acute in cases where the degree of necessary prestressing is not high [1-3].

Due to the fact that the prestressing of the flexible reinforced concrete elements’ working reinforcement significantly increases their crack resistance and reduces the deflections, but does not
affect the structural strength, it becomes necessary to investigate the possibility of replacing the working reinforcement prestressing with the alternatives simpler in technology. Moreover, the formation of cracks is often much more dangerous than large deflections due to the fact that it leads to reinforcement corrosion and a subsequent decrease in bearing capacity. First of all, from the alternative methods of increasing the crack resistance, it is worth highlighting fiber dispersed reinforcement of a reinforced concrete element. This method can significantly increase the crack resistance of the structure and allow it to work at a high loads level without cracking [4-8]. At the same time, the dispersed fiber reinforcement technology is simple and easy to implement in a building site.

Also, it may be relevant to replace the steel reinforcement of the compressed zone with fiber dispersed reinforcement in some cases, which will lead to a decrease in the consumption of steel and optimization of the bent elements’ reinforcement without reducing their bearing capacity.

However, it should be noted that fiber reinforcement is capable of replacing the prestressing of tensile reinforcement only to a certain extent, in cases where the crack formation moment compensated by prestressing is comparable to the effect of an increase in tensile strength of the fiber reinforced concrete [9,10].

In view of the foregoing, the authors plan to conduct a study of the fiber reinforcement presence effect on the strength and crack resistance of the reinforced concrete beams at various levels of the working reinforcement prestressing.

This article presents the results of the reinforced concrete beams strength and crack resistance theoretical calculations in the presence and absence of fiber reinforcement, a different number of working reinforcement rods and different steel grades, the presence and degree of their prestressing, as well as in the presence and absence of the compressed zone reinforcement.

Materials and methods
To perform a numerical experiment, the reinforced concrete beams from ordinary heavy concrete of class B25 were selected, and the same, using fiber reinforcement. The cross-section of all the samples was taken as 100x180mm, length 2 meters.

Steel working fittings varied and was presented, depending on the samples’ series, in the form of one, two and three rods Ø10A400 or Ø10A600. The compressed zone steel reinforcement is presented as 1Ø10A400, but in the two series samples from fiber concrete it is absent.

The samples were divided into 2 groups depending on the working reinforcement class used - with the A400 working armature and the A600 working armature. Each group consisted of the series comprising three samples: with one, two and three rods of working reinforcement, respectively. There were three series in the group with working class A400 reinforcement: the first – the beams without fiber reinforcement with steel reinforcement of the compressed zone, the beams with fiber reinforcement and the presence of the compressed zone reinforcement, and the beams with fiber reinforcement, where there is no steel reinforcement of the compressed zone.

In the group with working reinforcement of class A600, 3 series of samples were considered, similar to the above-mentioned, but with the class A600 working reinforcement. This group also includes 7 samples series, without fiber reinforcement with steel reinforcement of the compressed zone, and with varying degrees of the working reinforcement prestressing.

In a numerical experiment, the degrees of prestressing were considered: \( \sigma_{sp} = 0.35; 0.4; 0.45; 0.5; 0.55; 0.6; 0.65 \).

As a part of the study, a code was adopted for the samples under consideration, having the following form (Figure 1).
Figure 1. The prototype code sample

1- A reinforced concrete beam;
2- Used in manufacturing: n – ordinary heavy concrete; f - concrete with fiber reinforcement; p – the samples with prestressed reinforcement;
3- The number of the working reinforcement rods: 1, 2 or 3;
4- Number of the reinforcement bars in the compressed zone: 1 or 0;
5- Class of working fittings: 400 or 600.

The calculation of the prototypes was carried out according to the method described in BC 63.13330.2018 “Concrete and reinforced concrete structures. The main provisions. SNiP 52-01-2003”. A total of 39 prototypes were calculated for the first and the second group of the limiting states. The data obtained were processed and presented in Table 1, Table 2 and in the form of diagrams (Figure 2, Figure 3)

Discussions and Results
The results of the numerical experiment are given in Table 1 and Table 2, and are also presented in the form of diagrams in Figure 2 and Figure 3.

Table 1. The results of the prototypes calculation (group I)

| Series | Beam Code | A_S, [cm²] | A_S', [cm²] | Mult, [KN*m] | M crc, [KN*m] |
|--------|-----------|------------|-------------|--------------|---------------|
| 1      | Bn-11-400 | 0.785      | 0.785       | 4.04         | 1.23          |
|        | Bn-21-400 | 1.57       | 2.36        | 8.23         | 11.89         |
|        | Bn-31-400 | 2.36       | 0.785       | 12.28        | 3.26          |
| 2      | Bf-11-400 | 0.785      | 0.785       | 4.24         | 2.92          |
|        | Bf-21-400 | 1.57       | 2.36        | 8.34         | 12.82         |
|        | Bf-31-400 | 2.36       | 0.785       | 12.28        | 3.26          |
| 3      | Bf-10-400 | 0.785      | 0.785       | 4.23         | 2.68          |
|        | Bf-20-400 | 1.57       | 2.36        | 8.33         | 12.82         |
|        | Bf-30-400 | 2.36       | 0.785       | 12.28        | 3.17          |

Notes: 1) Columns 3 and 4 show the values of the working and compressed reinforcement area, respectively. 2) Column 5 shows the ultimate bending moment value. 3) Column 6 shows the moment of the crack formation normal to the longitudinal axis of the element.

Table 2. The results of the prototypes calculation (group II)

| Series | Beam Code | A_S, [cm²] | A_S', [cm²] | Mult, [KN*m] | M crc, [KN*m] |
|--------|-----------|------------|-------------|--------------|---------------|
| 1      | Bn-11-600 | 0.785      | 0.785       | 6.05         | 1.24          |
|        | Bn-21-600 | 1.57       | 2.36        | 11.6         | 1.37          |
|        | Bn-31-600 | 2.36       | 0.785       | 16.1         | 1.45          |
| 2      | Bf-11-600 | 0.785      | 0.785       | 6.23         | 2.95          |
|        | Bf-21-600 | 1.57       | 2.36        | 12.09        | 3.16          |
| Series | Beam Code | $A_s$, cm$^2$ | $A_s'$, cm$^2$ | $M_{ult}$, Kn*m | $M_{crc}$, Kn*m |
|--------|------------|----------------|----------------|----------------|----------------|
| 1      |            |                |                |                |                |
| 3      | Bf-10-600  | 0.785          | 0              | 6.21           | 2.84           |
|        | Bf-20-600  | 1.57           | 0              | 11.98          | 2.97           |
|        | Bf-30-600  | 2.36           | 0              | 16.75          | 3.17           |
|        |            | $\sigma_{sp}=0.35$ |              |                |                |
| 4      | Bp-11-600  | 0.785          | 0.785          | 6.05           | 1.86           |
|        | Bp-21-600  | 1.57           | 0.785          | 11.6           | 2.58           |
|        | Bp-31-600  | 2.36           | 0.785          | 16.1           | 3.3            |
|        |            | $\sigma_{sp}=0.4$ |              |                |                |
| 5      | Bp-11-600  | 0.785          | 0.785          | 6.05           | 2.08           |
|        | Bp-21-600  | 1.57           | 0.785          | 11.6           | 3.02           |
|        | Bp-31-600  | 2.36           | 0.785          | 16.1           | 3.9            |
|        |            | $\sigma_{sp}=0.45$ |            |                |                |
| 6      | Bp-11-600  | 0.785          | 0.785          | 6.05           | 2.29           |
|        | Bp-21-600  | 1.57           | 0.785          | 11.6           | 3.46           |
|        | Bp-31-600  | 2.36           | 0.785          | 16.1           | 4.64           |
|        |            | $\sigma_{sp}=0.5$ |            |                |                |
| 7      | Bp-11-600  | 0.785          | 0.785          | 6.05           | 2.51           |
|        | Bp-21-600  | 1.57           | 0.785          | 11.6           | 3.9            |
|        | Bp-31-600  | 2.36           | 0.785          | 16.1           | 5.32           |
|        |            | $\sigma_{sp}=0.55$ |          |                |                |
| 8      | Bp-11-600  | 0.785          | 0.785          | 6.05           | 2.73           |
|        | Bp-21-600  | 1.57           | 0.785          | 11.6           | 4.34           |
|        | Bp-31-600  | 2.36           | 0.785          | 16.1           | 5.99           |
|        |            | $\sigma_{sp}=0.6$ |            |                |                |
| 9      | Bp-11-600  | 0.785          | 0.785          | 6.05           | 2.95           |
|        | Bp-21-600  | 1.57           | 0.785          | 11.6           | 4.79           |
|        | Bp-31-600  | 2.36           | 0.785          | 16.1           | 6.67           |
|        |            | $\sigma_{sp}=0.65$ |          |                |                |
| 10     | Bp-11-600  | 0.785          | 0.785          | 6.05           | 3.15           |
|        | Bp-21-600  | 1.57           | 0.785          | 11.6           | 5.19           |
|        | Bp-31-600  | 2.36           | 0.785          | 16.1           | 7.28           |

Notes: 1) Columns 3 and 4 show the values of the working and compressed reinforcement area, respectively. 2) Column 5 shows the ultimate bending moment value. 3) Column 6 shows the moment of the crack formation normal to the longitudinal axis of the element.
**Figure 2.** Diagram of the cracking ultimate moment calculation results
Figure 3. Diagram of the calculation results for ultimate bending moment

Summary
Analyzing the study data, given in Table 1 and Table 2, as well as in Fig. 2 and Fig. 3, we can draw the following conclusions:

1. In flexible elements made of concrete B25 with high-strength reinforcement A400, fiber dispersed reinforcement makes it possible to abandon the steel reinforcement use in the compressed
zone for all the stretched zone percent reinforcement while maintaining the characteristics of the samples for strength and crack resistance.

2. In flexible elements made of concrete B25 with high-strength reinforcement A600:
- the fiber reinforcement introduction makes it possible to abandon the elements’ reinforcement in the compressed zone, regardless of the reinforcement percentage in the stretched zone;
- the introduction of fiber reinforcement allows to reduce the tensile reinforcement high-tensile reinforcement prestressing degree by half while maintaining almost the same ultimate moment, cracking time, deflections and crack opening widths in the elements’ operational stages.

References

[1] Joshi Suhas S, Thammishetti Nikesh, Prakash Suriya S 2018 Efficiency of steel and macro-synthetic structural fibers on the flexure-shear behaviour of prestressed concrete beams Engineering Structures 171 47–55
[2] S Furlan Junior, J Bento de Hanai 1999 Prestressed fiber reinforced concrete beams with reduced ratios of shear reinforcement Cement & Concrete Composites 21 213–221
[3] Berdichevsky G I, Svetov A A, Kurbatov L G, Shikunov G A 1984 Pre-stressed steel-reinforced concrete ribbed beams 6 × 3 m in size for coatings Concrete and reinforced concrete 4 33–34
[4] Mayilyan L R, Mayilyan R L, Shilov A V 1997 Strength calculation of flexible fiber-reinforced concrete elements with high-strength reinforcement Izvestiya Vuzov. Construction and architecture 4 4–7
[5] Mayilyan R L, Mayilyan L R, Shilov A V, Abdallah M T 1995 Flexible elements from expanded clay concrete with high-strength reinforcement without prestressing and partial Bulletin of the higher educational institutions. Construction 12 19–23
[6] SP 52-104-2006 *. Steel-fiber concrete structures, Moscow, OJSC "Research Center Construction", 2010.
[7] Kholmyansky M M, Kurilin V V, Edneral A F 1991 Steel-fiber concrete with amorphous fiber Concrete and reinforced concrete 6 9–10
[8] Trambovetsky V P 1974 Concrete reinforced with dispersed reinforcement Concrete and reinforced concrete 2 40–42
[9] Radkova I N, Gritsaenko V I, Koval I V 2012 Effective hardening component of reinforced concrete structures - steel fiber Casting and metallurgy 1 38–42
[10] Pukharenko Yu V, Panteleev D A, Morozov V I, Magdeev U Kh 2016 Strength and deformability of poly-reinforced fiber-reinforced concrete using amorphous metal fibers Academia. Architecture and construction 1 107–111