# Flexural Strength of Fiber Reinforced Concrete Structures

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**Abstract**. The paper presents an analysis of dispersed reinforcement methods. Metal fibres have been used when conducting the experiment. It has been shown that the reinforcement of concrete with metal fibers can significantly increase crack resistance for structures made of fiber-reinforced concrete in comparison with similar reinforced concrete structures.It should be noted that blocking crack development and blocking the possibility of the main cracks formation is achieved in structures made of fiber-reinforced concrete due to a more uniform distribution of forces arising in concrete. The results of an experiment on the reaction of beams with dispersed reinforcement to a bending load have been presented. The calculation of stretched and bending element with dispersed and combined reinforcement has been performed. The calculation showed that the use of combined reinforcement in structures can increase their overall bearing capacity. The comparison of the calculation and experiment results has shown a showed good convergence.

Modern construction offers great opportunities and is constantly evolving. It is inextricably linked with the solution of problems to improve the efficiency such as reducing lab or intensity; reduction in material costs; application of progressive materials.

Nowadays, concrete is the leader among other building materials. But along with this concrete has a significant drawback: it does not perceive tensile stresses well. So there is a need for reinforcement, which significantly extends the operational lifetime of structures.

Rod reinforcement does not affect the crack resistance of concrete so much. Dispersed concrete reinforcement, in which the reinforcing component (steel fibers) is evenly distributed in the concrete mixture is becoming increasingly popular in the world. This type of reinforcement opens up broad prospects in constructive and technological terms.

Dispersed reinforcement is widely used in many countries. This is explained by the fact that specialists are pursuing the goal of increasing tensile strength and crack resistance.

The aim of the work is to calculate stretched and bendable elements with dispersed and combined reinforcement and to compare the results with experimental data.

Currently there are three main reinforcing fibers: fibersmade of thin steel wire; glass fibers; fibers based on polypropylene.

The elastic modulus of steel fiber reinforcement is 6 times greater than that of concrete. The elastic modulus of fiberglass materials is 3 times greater than that of concrete. The elastic modulus of fibers based on polypropylene is a quarter of that of concrete. Thus, we conclude that steel fibers are the most promising for concrete reinforcement. Examples of steel fibers are shown in Fig. 1.

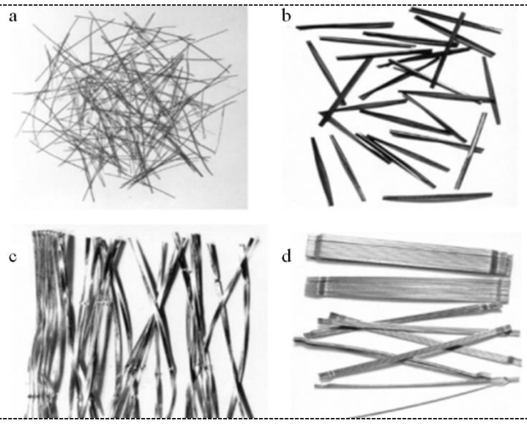


**Figure 1.** Type of steel fibers: a –made of wire; b - made of slab; c - made of sheet; d - "Dramix" (Belgium).

Let's consider the results of experimental studies on the strength of steel fiber concrete (SFC) samples under static load. The tests were performed on beams with dimensions of 10x10x1650 mm, reinforced with steel fibers with a diameter of 0.8 mm and rod reinforcement $d$ = 6 mm, with a coefficient of rod reinforcement $\mu_f$ = 0.00471. Calculated fiber resistance $R_f$ = 950 MPa; fiber elastic modulus $E_f$ = $1.9 \cdot 10^5$ MPa. The results of the experiments are shown in fig. 2.

The calculation scheme shown in Fig. 3. for the experiment and calculations.

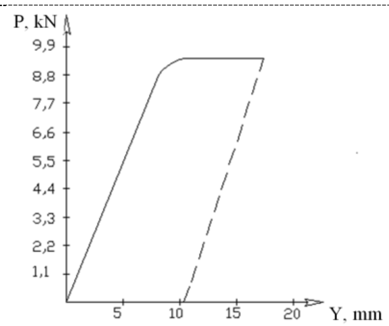


**Figure 2.** Graph of P-Y dependence.

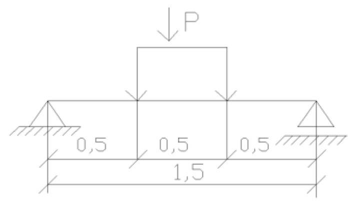


**Figure 3.** Diagram of loading a beam located on two supports.

Determine the calculated tensile strength:

$$R_{fbt} = m_1\left[k_1 k_{or}^2 \mu_{f\gamma} R_f\left(1-\frac{l_{f,an}}{l_f}\right)+0.1R_b\left(0.8-\sqrt{2\mu_{f\gamma}-0.005}\right)\right]=$$

$$=1.1\cdot\left[0.5\cdot 0.53^2\cdot 0.00471\cdot 600\left(1-\frac{0.4}{100}\right)+0.1R_b\left(0.8-\sqrt{2\cdot 0.00471-0.005}\right)\right]=0.38M\Pi a,$$

where $m_1 = 1.1$; $k_{or} = 0.53$; $\mu_{f\gamma} = 0.00471$; $R_f = 600$.

The design resistance in compression:

$$R_{fb} = R_b + \left(K_n^2 \varphi_a \mu_f R_f\right),$$

where $K_n = 0.481$ is the coefficient by which the work of fibers in the design section is taken into account; $\varphi_a$ is the coefficient of efficiency of indirect reinforcement with fibers:

$$\varphi_a = \frac{5+L}{1+4.5L} = \frac{5+0.04}{1+4.5\cdot 0.04} = \frac{5.4}{1.18} = 4.2;$$

$$L = \frac{K_n^2 \mu_{fn} R_f}{R_b} = \frac{0.023\cdot 0.00471\cdot 600}{14.5} = 0.04;$$

$$R_{fb} = 14.5 + (0.23\cdot 4.2\cdot 0.00471\cdot 600) = 17.2 \text{ MPa}.$$

Determine the values of the reduced reinforcement coefficients:

- in the compressed zone: $\mu_{fa} = \mu_{f\gamma} K_n^2 = 0.00471\cdot 0.23 = 0.00108;$
- in the extended zone: $\mu_{fa} = \mu_{f\gamma} K_{or}^2 = 0.00471\cdot 0.28 = 0.00132.$

Determine the value of the boundary relative height of the compressed zone:

$$\varepsilon R = \frac{\omega}{1+\frac{\sigma_{sR}}{\sigma_{sc,u}}\left(1-\frac{\omega}{1.1}\right)} = 0.73,$$

where $\omega$ is SFC compression zone characteristic;

$$\omega = \varphi - 0.008\cdot R_b = 0.85 - 0.008\cdot 14.5 = 0.734;\ \varphi = 0.85;\ \sigma_{sR} = 0.$$

To calculate bending elements, we apply the condition $M \le M_{ult}$,where $M_{ult}$ is the maximum bending moment in the design section [2].

For fiber reinforcement take $M_{ult} = R_{fb}\cdot b_x \cdot 0.5\cdot h.$

Determine the value of the height of the compressed zone:

$$x = \frac{R_{fbt}\cdot h}{R_{fb}+R_{fbt}} = \frac{0.38\cdot 0.1}{0.38+17.2} = 0.002;\ M_{ult} = 17.2\cdot 0.1\cdot 0.002\cdot 0.5\cdot 0.1 = 18.56\ kgf\cdot m.$$

For combined reinforcement this formula was used:

$$M_{ult} = R_{fb}\cdot b_x \cdot \left(b - \frac{x}{2} - a\right) + R_{sc}\cdot A_s \cdot (y-x-a) - R_{fbt}\cdot b\cdot (h-x)\cdot \left(\frac{h-x}{2} - a\right).$$

Fig. 4 shows a stress diagram and a diagram of load application in the design section of a bending fiber-concrete beam, when calculating the strength (with fiber reinforcement), and Fig. 5 shows stress diagram and diagram of load application in the design section of a bending fiber-reinforced concrete beam in strength analysis (with combined reinforcement) [2].

The height of the compressed zone x is determined from the formula:

$$R_{sc}\cdot A_s + R_{fb}\cdot b\cdot x = R_{fbt}\cdot b\cdot (h-x) + R_s\cdot A_s;\ \ x = 0.002;$$

$$M_{ult} = 17.2\cdot 10\cdot 0.002\cdot \left(10 - \frac{0.002}{2} - 1.2\right) + 218\cdot 0.002\cdot (10-1.2-1.2) -$$

$$-0.38\cdot 10\cdot (10-0/002)\cdot \left(\frac{10-0.002}{2} - 1.2\right) = 49.4\,kgf\cdot m$$

Calculation of elements made of fiber-reinforced concrete, taking into account the opening of cracks, consists of calculations on the fact of the cracks formation and on their opening.

The maximum cracking moment $M_{\max} = 28.5\ kgf\cdot m.$

The moment of cracking $M_{crc} = W_{pt} R_{bt,ser}$, where $W_{pt}$ is the value of section modulus in the extreme stretched fiber

$$W_{pt} = \frac{2\left(I_{bc} + \alpha_f I_{fc1} + \alpha_f I_{ft1}\right)}{h-x} + S_{bt};\ W_{pt} = 0.013m^3;\ M_{crc} = 0.013 \cdot 1.55 = 20.9 kgf \cdot m,$$

$M_{\max} = 28.5\ kgf \cdot m > M_{crc} = 20.9 kgf \cdot m,$ the condition is met.

The calculation of SFC fragments of structures is performed according to the condition of normalizing deflections: $f \le f_{ult}$; $f = \int_0^1 \overline{M_x} \left(\frac{1}{r}\right)_{tot,x} dx$; $\left(\frac{1}{r}\right)_{tot,x} = \left(\frac{1}{r}\right)_1 + \left(\frac{1}{r}\right)_2 = 0.84 + 1.34 = 2.18,$

where $f$ is the deflection value of the SFC fragment of the structure from the external load; $f_{ult}$ is the maximum deflection; $\overline{M_x}$ is from the action of a unit strength, the value of the bending moment in the design section x; $\left(\frac{1}{r}\right)_{tot,x}$ in the design section *x* is the value of the maximum curvature of the element arising from the external load effect; $\left(\frac{1}{r}\right)_1$ and $\left(\frac{1}{r}\right)_2$ is the curvature from constant, short-term and long-term loads; $f = 6.54 mm = 0.65 sm;$ $f_{ult}$ accept no more than 1/150 of the span length; $f_{ult} = 1 sm > f = 0.65 sm.$

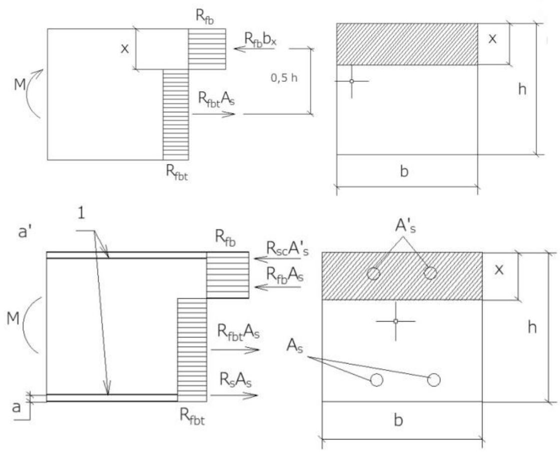


**Figure 4.** Stress diagram and load application diagram in the design section of a bending fiber-reinforced concrete beam, when calculating the strength (with fiber reinforcement) [2].

The conducted studies allow us to conclude that when comparing the levels of crack resistance of reinforced concrete structures and structures made of fiber-reinforced concrete, the latter have an advantage in this parameter. This advantage is achieved due to the peculiarities in the structure of fiber-reinforced concrete, since dispersed reinforcement contributes to a more even distribution of forces within the structure solid. Thus, a less favorable environment is created for the development of cracks in fiber-reinforced concrete, due to which the development of main cracks also stops.

It was found that when using combined reinforcement, the overall bearing capacity of the structure increases.

The calculation of bending elements with dispersed and combined reinforcement was performed. Comparison of the results obtained with the experimental data showed good convergence.