Dispersed reinforcement of columns of a high-rise building

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Abstract. The article deals with the application of combined reinforcement of concrete with steel and basalt fibers. A model of a high-rise building was calculated in the LIRA-SAPR 2013 software. Design and characteristic strength of steel fiber and basalt fiber reinforced concretes to compression and tension and the initial elastic modulus were determined to calculate the model. Comparison of the effect of B40 concrete steel fiber reinforced concrete (SFRC) and basalt fiber reinforced concrete (BFRC) on column reinforcement was performed by comparing the required areas of reinforcement, as well as the percentage of reinforcement, taking into account crack resistance. The total area of reinforcement decreased with the addition of steel fiber by 36.9% and basalt fiber by 39.9%. The percentage of reinforcement also decreased, taking into account crack resistance, from 0.694 for columns with concrete B40 to 0.437 for SFRC columns and to 0.417 for BFRC columns. The addition of fiber increases the strength characteristics of concrete: compressive strength increased by 35.8% and 77.2%, tensile strength by 150.2% and 75.7%, crack resistance by 37% and 39.9%, the initial modulus of elasticity of the material increased by 8.7% and 3.7% for SFRC and BFRC respectively compared with concrete B40.

1 Introduction

Characteristics of concrete as a composite material depend on the characteristics of its components. Reinforcement of concrete allows compensating for the shortcomings of concrete, especially its main disadvantage – low tensile strength. The most common is reinforcement with steel bars. But it could be replaced by more efficient reinforcement such as disperse reinforcement, which significantly decreases the construction weight and improves other properties. The use of fiber is the most common way to produce dispersed reinforced concrete. The structure of fiber-reinforced concrete is a fiber material coated with a uniform layer of concrete. Fiber reinforcement is one of the most effective ways of reinforcing due to the fact that it strengthens concrete in all three directions [1, 2]. As fiber reinforcement, fibers of artificial or natural materials, textile fabrics, carbon tubes, etc. can be used. Each type of material has its advantages and disadvantages, for example, glass or basalt fiber has a high modulus of elasticity, but both types of fiber have a low alkaline

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resistance [3-6]. The resistance to different kinds of impacts and the ability of surface modification are the main benefits of carbon fiber. However, the drawback of carbon fiber is its tendency to cluster [7, 8]. Another carbon type of fiber is carbon nanotubes (CNTs). The big interfacial contact area and low weight (due to size in nm) and the proportions of nanotubes make it possible to distribute them on a much lesser scale compared to other types of fibers [9, 10]. Not only fibers can be used, but textile fabrics, counting those made from natural fibers. However, natural decomposition is their main disadvantage. But due to their low cost, ease of manufacture and environmental friendliness, they find application in construction [11, 12].

High-strength concrete is concrete with high mechanical properties; it has very high strength (compression more than 150 MPa, tensile more than 8 MPa). Dispersed reinforcement is also used in producing of the high-strength concrete [13]. Such concrete is more durable and longeval, has increased resistance to various chemicals and to freeze-thaw cycles. The combined use of different types of fibers allows to achieve the higher performance due to possibility of different fibers compensate each other's drawbacks [14, 15]. Not only the type of fiber affects the concrete performance, but there are also method and external conditions of reinforcement [16, 17].

Nowadays, steel fiber reinforced concrete (SFRC) is the most widespread type of dispersed reinforcement. Steel fiber is easy to manufacture and easy to handle. Its advantages are its high modulus of elasticity and line expansion coefficient, close in value to the value of this coefficient of concrete. Compared to concrete, SFRC has increased strength, crack resistance, impact ductility, heat, frost and wear resistance and significantly reduce the thickness of structures. One of the main disadvantages of steel fiber is its susceptibility to corrosion. The small diameter of the fiber contributes to the rapid destruction of fiber. Fiber can be protected by using sheet steel fiber obtained at high manufacturing temperatures or with anti-corrosion coatings [13, 18-20].

Another popular type of fiber is basalt fiber. Basalt fiber has a high modulus of elasticity, absolute incombustibility (hence, heat resistance), non-toxicity, high adhesion and chemical resistance. Basalt fiber reinforced concrete (BFRC) is characterized by high crack resistance and increased impact strength, tensile strength, frost resistance (up to 500 cycles) and high corrosion resistance. The concrete mix hardens faster, its adhesion to surfaces increases. Since basalt is a natural material, BFRC is an environmentally friendly material. The use of fiber reduces the consumption of cement and water in the concrete production. The main disadvantage of basalt fiber is corrosion during the hydration of Portland cement. There are several control methods, for example, the most common is the introduction of silica-containing materials, in view of their increased activity to the alkaline environment of hydrating cement (e.g. micro- and nanosilica) [4, 21-23].

The aim of this study is to compare the strength characteristics of concrete B40, steel fiber reinforced concrete and basalt fiber reinforced concrete when reinforcing columns of a high-rise building. To do this, the following tasks:

- to calculate strength characteristics of steel fiber reinforced concrete;
- to calculate strength characteristics of basalt fiber reinforced concrete;
- to calculate the model of a high-rise building in the LIRA-SAPR 2013 using concrete of class B40, steel fiber and basalt fiber reinforced concretes with calculated strength characteristics;
- to compare the results of reinforcement of columns made of concrete B40 and fiber reinforced concretes.

2 Materials and methods

2.1 The Calculated Building

The calculated building is a high-rise 31-story office building with 2 underground floors. Projected building height is 107.3 m. A finite element model of a high-rise building was made in SAPFIR 2015 modelling software and calculated in the LIRA-SAPR 2013 software package. Building structure is a monolithic reinforced concrete frame, consisting of load-bearing columns, walls and slabs, rigidly interconnected and forming a single spatial structure.

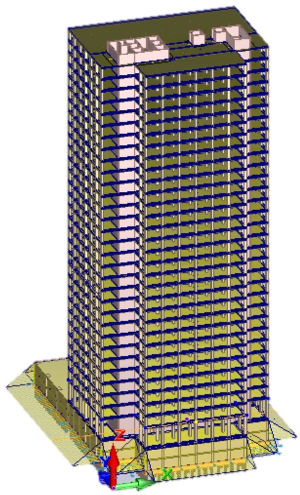

Fig. 1. The design model of the building.

Bearing reinforced concrete columns with a cross-section of 800x800 mm (concrete B40, column spacing 4.5 m) are designed in the building. The stiffening core consists of elevator units and staircases, in the form of monolithic walls 300 mm thick (concrete B40). The outer walls of the underground floors - reinforced concrete 300 mm (concrete B40). Slabs are solid-cast reinforced concrete, 300 mm thick (concrete B40). Foundation for the building is piled with grillage, solid-cast reinforced concrete slab 1200 mm thick (concrete B45). The footing depth is 6.4 m. Piles are bored reinforced concrete of circular cross section with a diameter of 620 mm, length 20 m. The enclosing walls of the aboveground part are designed as a hinged glazing system based on the slabs. The design scheme is presented in Fig. 1.

2.2 Load summary

The calculation of the building was executed on the basic load combination, according to Russian Code of Practice SP 20.13330.2016 Loads and actions. Loads were collected taking into account design solutions and the functional purpose of the building. Snow region – III, wind region – II for St. Petersburg, Russia. Basic load combination loads are dead load, constant load, temporary long-term load, short-term load.

2.3 Characteristics of materials

Calculation of the model requires the design and characteristic strength of fiber reinforced concrete to compression and tension and the initial elastic modulus. The design compressive and tensile strengths of fiber reinforced concrete depend on the class of compressive strength of the concrete matrix, the percentage of fiber reinforcement by volume, fiber strength. The design characteristics of fiber concrete were obtained on the base of concrete B40 with the addition of fiber cut from steel sheet according to specification TU 1276-001-70832021 with a length of 20 mm and a nominal diameter of 0.3 mm and with the addition basalt fiber according to standard STO 23.99.19-005-57231417-2016 with a length of 20 mm and a nominal diameter of 0.1 mm. Materials characteristics and presented in Table 1.

Table 1. Characteristics of materials for calculating the parameters of fiber concrete

Concrete B40	
Modulus of elasticity, MPa	E_b=36000
Design resistance to axial compression, MPa	R_b=22.0
Design resistance to axial tension, MPa	R_{bt}=1.4
Characteristic resistance to axial compression, MPa	R_{bn}=29.0
Characteristic resistance to axial tension, MPa	R_{btn}=2.1
Reinforcement AIII	
Modulus of elasticity, MPa	$E_s=2\cdot10^5$
Design resistance to tension for ultimate limit states of longitudinal reinforcement, MPa	R_s=365
Design resistance to tension for ultimate limit states of transverse reinforcement, MPa	R_{sw}=290
Design resistance to tension for serviceability limit states, MPa	$R_{s,ser}$=390
Design resistance to compression for ultimate limit states, MPa	R_{sc}=365
Steel fiber	
Modulus of elasticity, MPa	$E_f=2.1\cdot10^5$
Design resistance to tension for serviceability limit states, MPa	$R_{f,ser}$=550
Design resistance to tension for ultimate limit states, MPa	R_f=500
Basalt fiber	
Modulus of elasticity, MPa	$E_f=1.1\cdot10^5$
Design resistance to tension for serviceability limit states, MPa	$R_{f,ser}$=3000
Design resistance to tension for ultimate limit states, MPa	R_f=2727

Thus, the following values were obtained for SFRC and BFRC, presented in Table 2 and compared with B40 concrete in Table 3.

Table 2. Characteristics of steel fiber reinforced concrete and basalt fiber reinforced concrete

Characteristic	**SFRC**	**BFRC**
Modulus of elasticity, MPa	E_{sfb}=39132	E_{bfb}=37332
Design resistance to axial compression, MPa	R_{sfb}=29.87	R_{bfb}=38.98
Design resistance to axial tension, MPa	R_{sfbt}=3.503	R_{bfbt}=2.46
Characteristic resistance to axial compression, MPa	R_{sfbn}=32.86	R_{bfbn}=50,679
Characteristic resistance to axial tension, MPa	R_{sfbtn}=3.853	R_{bfbtn}=3.12

Table 3. Comparison of materials

Characteristic	**Concrete B40**	**SFRC**	**BFRC**
Modulus of elasticity, MPa	36 000	39 132	37 332
Design resistance to axial compression, MPa	22	29.87	38.98
Design resistance to axial tension, MPa	1.4	3.503	2.46

3 Results and discussion

The influence of the addition of steel fiber and basalt fiber on the strength characteristics of concrete is considered. As a result of the calculation of the model, the required values of the reinforcement areas for the building columns and the percentage of reinforcement, taking into account the crack resistance, were determined. The calculation results are presented in Fig. 2, Fig. 3.

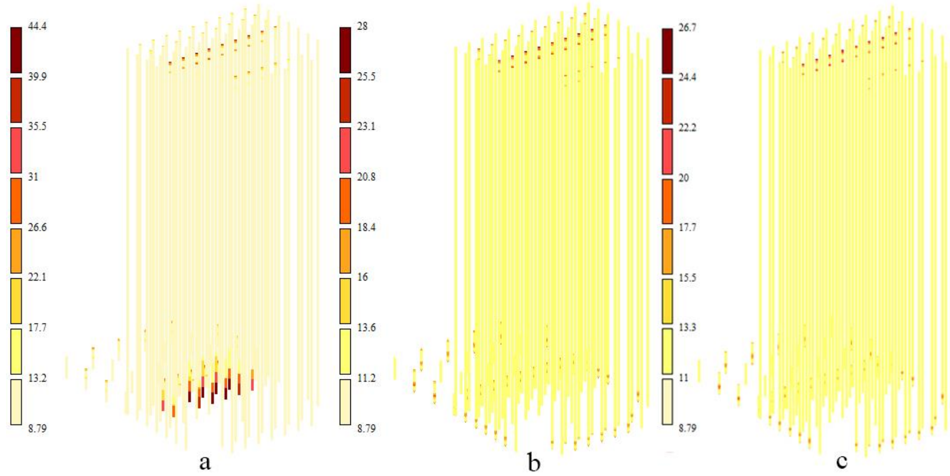

Fig. 2. Distribution of the area of longitudinal reinforcement (a – concrete B40; b – steel fiber reinforced concrete; c – basalt fiber reinforced concrete), cm^2.

In Fig. 2, the scale displays the values of the required reinforcement area in cm2. In Fig. 3, the scale displays the required percentage of reinforcement, taking into account the crack resistance. The total area of reinforcement (the sum of the areas of angular, lower and upper longitudinal reinforcements) of the most loaded element is of the least value in the case of reinforcing with BFRC 26.7 cm2, slightly less than the value obtained for SFRC (28 cm2). For concrete B40 value is 44.4 cm2. The percentage of reinforcement, taking into account crack resistance, decreased for fiber reinforced concretes. The maximum value is for columns with concrete B40 is 0.694, for columns made of SFRC is 0.437 and for columns made of BFRC is 0.417.

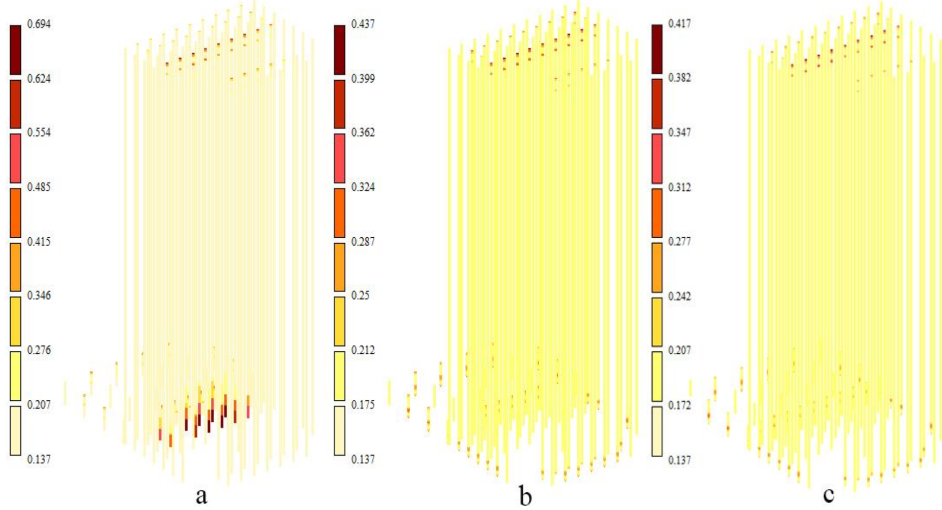

Fig. 3. Percentage of reinforcement taking into account crack resistance (a – concrete B40; b – steel fiber reinforced concrete; c – basalt fiber reinforced concrete).

4 Conclusions

The addition of fiber increases the strength characteristics of concrete: compressive strength increased by 35.8% for steel fiber and 77.2% for basalt fiber, tensile strength increased by 150.2% for steel and by 75.7% for basalt fibers.The total area of reinforcement decreased with the addition of steel fiber by 36.9% and basalt fiber by 39.9% compared with concrete B40.

The addition of fiber rises the crack resistance of concrete by 37% for steel fiber and 39.9% for basalt fiber compared with concrete B40.The modulus of elasticity of the material increased by 8.7% for steel fiber and by 3.7% for basalt fiber compared with concrete B40.

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