Application of fiber-reinforced concrete in high-rise construction

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Abstract. In this research, we study the use of fiber-reinforced concrete, including steel fiber-reinforced concrete in the construction of outrigger floors of a high-rise building. The definition and classification of fiber-reinforced concrete as a construction material, the methodology for calculating high-rise buildings using fiber-reinforced concrete, the advantages and disadvantages of this composite material, and the specifics of its use are formulated. The domestic and foreign experience in use of fiber-reinforced concrete is analyzed. The rationale for its use on the experience of construction of residential building in seismically active regions is given. A comparative analysis of concrete and fiber concrete use in the outrigger floors' construction is carried out.

1 Introduction

Every year the level of construction complexity inevitably grows. Most of the total number of modern constructions is made up of technically complex, unique objects with an increased degree of responsibility - high-rise and long-span buildings, buried structures, which creates new tasks due to ensuring the safety and reliability of buildings and structures under construction, reducing the negative impact on urban infrastructure within the zone influence.

Partly, the demand for unique buildings is formed by huge corporations and highly developed countries, where the priority is the functionality of the premises and the possibility of placing multidirectional organizations in the same building.

Unique buildings and constructions have always been proof of the engineering achievements, individual specialists could think over the construction of such objects, but this gave rise to problems such as irrational consumption of materials, small spans, and the huge sizes of structural elements [1-3].

The urgency of the problem is to ensure the strength and stability of the unique building structure with a height of more than 100 meters through the use of modern new material - fiber-reinforced concrete in the construction of outrigger floors [9].

The object of the study is the characteristics and behavior of fiber-reinforced concrete in the supporting structures of the outrigger floor of a unique building.

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The subject of the study is the possibility of using fiber-reinforced concrete in the supporting structures of a unique building in the construction of outrigger floors.

The aim of the study is to determine the effectiveness of fiber-reinforced concrete use in the outrigger floors' construction of unique buildings.

2 Results

Due to the fact that the prevailing load for high-rise buildings is wind, the main indicators of the building's operability and efficiency are horizontal movements and fluctuation pulsations. To compensate for these impacts and reduce the risks of building instability, it is reasonable to decide on using fiber concrete in the construction of an outrigger floor [4].

Outriggers are systems of trusses of a high-rise building that serve as a connecting element of the central core and columns of the fence. Unlike the classic floor of a skyscraper, radial composite walls with a height of two floors (equal to one outrigger one) pass through the outrigger floors. Each of the steel trusses is surrounded by reinforcement and concreted. Today, the Lakhta Center composite outrigger radial walls in St. Petersburg are a solution that is first used in Russia for high-rise buildings. The design of the Lakhta Center building can be seen in Fig. 1, Fig. 2.

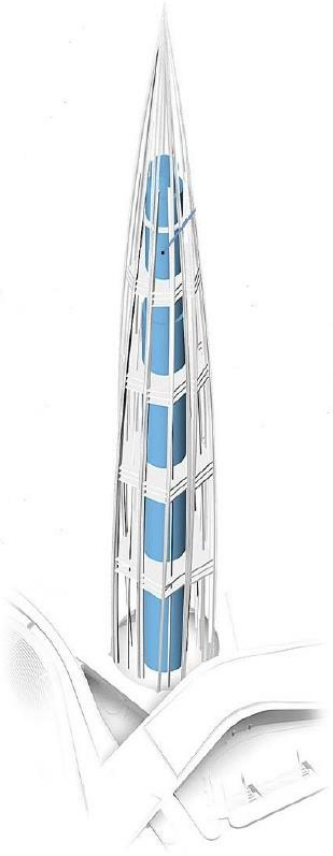

Fig. 1. The structure core of "Lakhta Center"

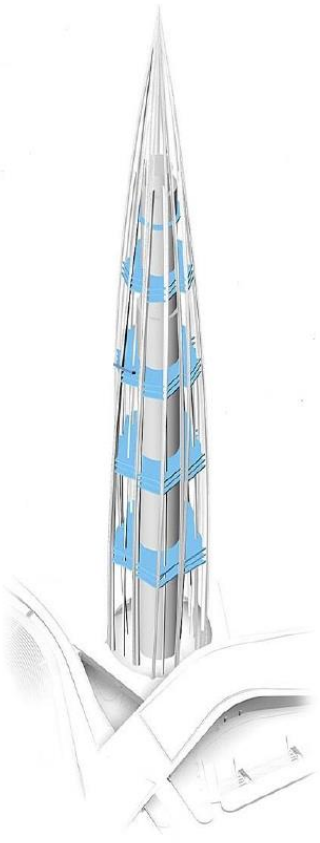

Fig. 2. Outrigger floors in the construction of "Lakhta Center"

For ultra-tall buildings, it is extremely important to use outrigger systems with a full frame structure along the perimeter. The large size of the core is crucial to increase the rigidity of the structure during twisting, since the external frame provides it only partially. Testing in a wind tunnel and monitoring the behavior of already operating high-rise buildings have confirmed that the building frame experiences the greatest torsional stress, which means that determining the torsional stiffness of the building frame is extremely important [7].

The monolithic structures properties' variety seems possible to increase through the use of fiber-reinforced concrete.

This material belongs to the kind of composite materials - high-strength concrete with reinforcing fibers uniformly distributed in the mass [10-11] (Fig. 3).

Fiber with reinforced (arm) fiber increases the cohesion of the material's structure, its adhesive properties [12]. The structure of the material is shown in Fig. 4

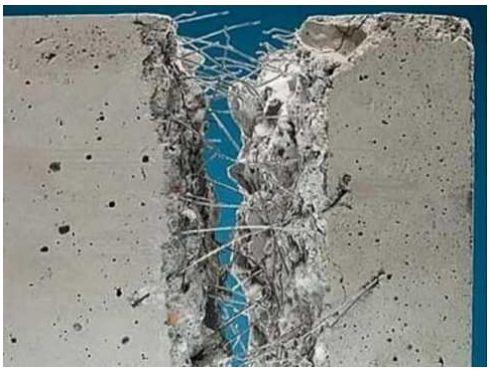

Fig. 3. Fiber-reinforced concrete look

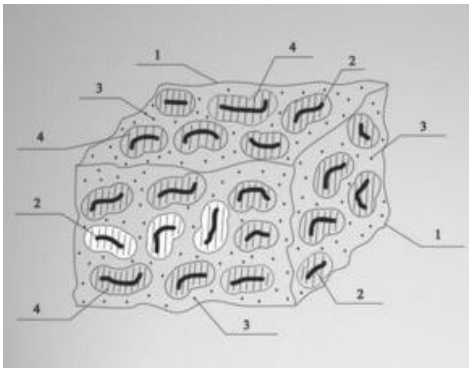

Fig. 4. Structure of fiber-reinforced concrete
1 - the boundary of the macroscopic cell;
2 - fiber;
3 - matrix of concrete;
4 - zone of contact interaction for reinforcing fibers with concrete.

According to the material's manufacturing, the fibers are produced of the following types: natural, synthetic, glass, metal. The physical and mechanical characteristics depend on the type of fibers contained in the concrete. Fiber makes it possible to avoid material's shrinkage, abrasion and cracking, including one due to the random arrangement of material fibers in the concrete matrix.

Due to the large amount of fiber in the concrete, a decrease in strength can occur, therefore, fiber should be added to the concrete mixture in a ratio of 0.1 to 3% of the total mass of the components used [13].

For the evaluation purposes, in order to assess the possibilities of using outriggers and the use of fiber-reinforced concrete in their structures and to perform a comparative analysis, several models were created with various design solutions with and without outriggers. The calculation of the building frame is performed using the SCAD program complex (PC). In the calculation, the elements of the calculation scheme were assigned the stiffness characteristics of the stair-lift nodes' walls, columns, floor slabs, slab grillage and piles.

In order to increase the building's resistance to wind loads, outrigger floors are added. When setting the rigidity of the outrigger systems, SCAD design-construction company

(DCC) is guided by SP 52-104-2006* “Steel-fiber concrete structures”, the main load combinations and form the CSC (Calculation of Stresses Combinations) and CMC (Calculation of Movements’ Combinations) are calculated.

Figures 5, 6 show the movements of a high-rise building with one outrigger made using fiber-reinforced concrete.

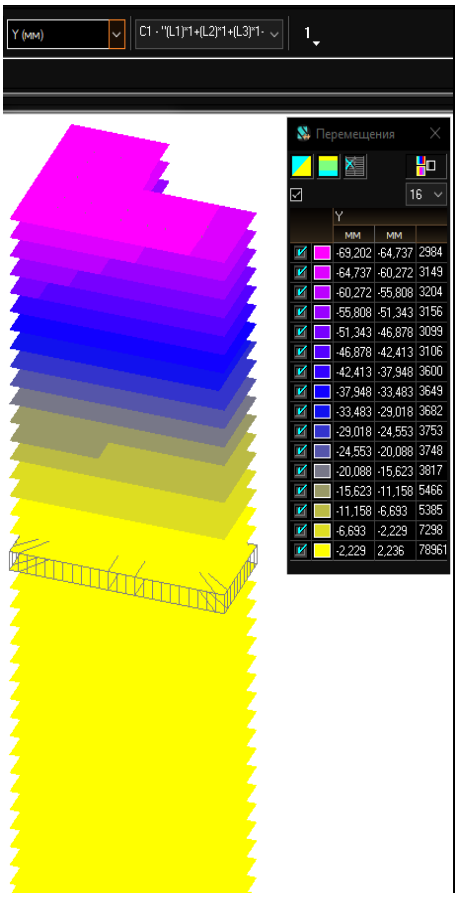

Fig. 5 Movement along the X axis of a building with one outrigger of fiber-reinforced concrete.

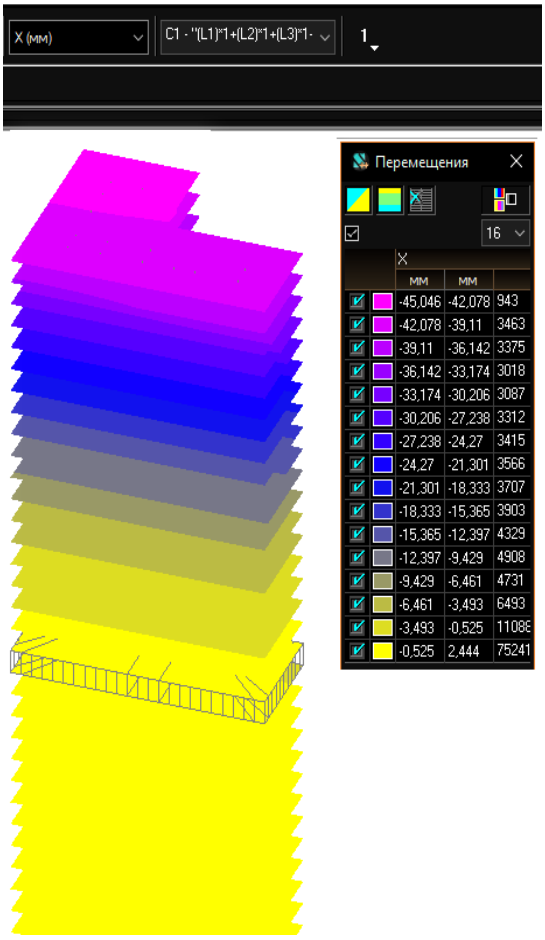

Fig. 6 Moving along the Y axis of a building with one outrigger of fiber-reinforced concrete.

According to this principle, the calculations of the building were performed for various structural solutions. The results obtained are summarized in Table 1.

Based on the performed research, we can draw certain conclusions. It is important to be able to combine architectural and planning solutions with structural solutions so that they work together.

Buildings that have a large height, take on an increased wind load. Outrigger floors should be installed to reduce horizontal movements and vibrations of the building. The more outrigger floors there are in the building, the less horizontal movements and fluctuations will be during its maintenance.

Based on the results of the performed research, we can say that the outrigger floor is an effective solution to reduce the horizontal movements of the building.

Table 1. Comparison of the movements for high-rise buildings of various types

	Horizontal movements, mm	
Type of building	*along the X axis*	*along the Y axis*
Without outriggers	194.479	415.591
With one outrigger	44.499	73.089
With two outriggers	1.259	2.262
With one fiber reinforced concrete outrigger	45.046	69.202
With two fiber reinforced concrete outriggers	2.528	2.188
With one steel outrigger	9.252	13.535

The introduction of steel fiber concrete shows that steel is currently the best option for the material of outrigger systems construction. This is due to the fact that when the load-bearing structures of a building are working, stiffness is greatly influenced by the value of the elastic modulus of the material. The value of the elastic modulus for steel is 4 times greater than for steel fiber concrete and 6 times more than concrete of class B30 [8].

In Russia, fiber-reinforced concrete is used in monolithic construction mainly in thick slabs, and is almost never used in prefabricated structures.

However, with the increase in the number of high-rise residential buildings, sooner or later it will force everyone to switch to it, because the leading construction companies around the world give their preference to this kind of concrete.

The main advantage of using fiber-reinforced concrete in monolithic construction is definitely earthquake resistance. Often, construction in seismically active areas is complicated by a number of reasons such as mountainous terrain and the negative impact of natural conditions.

The consequences can be different: landslides and landslipes, destruction of buildings, cracks in the soil up to 1 meter, curvature of the railway tracks. As a result of constructing residential buildings exactly in earthquake-prone areas, there is a need to increase the stability of the buildings, which can be achieved by laying a monolithic foundation [5-6].

The experience of using fiber-reinforced concrete in such developed countries as the United States of America, Canada, Great Britain, Japan, Germany, Italy, France and Australia, has shown significant technical and economic efficiency of the use of fiber-reinforced concrete in building structures.

Fiber concrete is used abroad in the construction and reconstruction of airfield and road surfaces, in underground and hydraulic structures, in thin-walled structures. In Japan, fiber-reinforced concrete is used in earthquake-prone areas.

Unique buildings around the world are classified as buildings with an increased level of liability and reliability class. Compared to conventional buildings, the cost of their construction is much higher. This is determined by the complexity of the construct, construction technology, an increased degree of safety required at all stages of production.

In this regard, new technologies and materials, such as outrigger floors using fiber-reinforced concrete, were considered. The use of these two elements in construction can make the structure stable and safe.

3 Conclusion

Steel fiber concrete is a modern material that has improved characteristics compared to ordinary concrete, but when introduced into the outrigger system, it did not show any special differences with ordinary concrete. Based on the small economic difference in cost between concrete and fiber-reinforced concrete, we conclude that steel fiber-reinforced concrete is better used to increase the strength characteristics, and not to reduce the horizontal movements of the building.

Outrigger floors have a huge variety, both of type and location in the building, which to some extent makes them unique in solving problems of wind load resistance.

The practical significance of the study lies in the fact that a comparative analysis of concrete and fiber-reinforced concrete performance in horizontal movements from the wind load was performed.

Modern problems require innovative solutions, so instead of ordinary concrete there comes fiber reinforced concrete, improved in all respects. All buildings become heavier, taller, more complex and can resist huge loads. Therefore, in order not to modify the construct, adding extra columns, bonds and stiffness diaphragms, to thicken floor slabs, walls, a newer and unique material - such as fiber-reinforced concrete – can be used. Due to the huge number of fiber types, it can be used anywhere.

The results of the study allow concluding that fiber-reinforced concrete can be used in outrigger structures as the main material. Fiber-concrete may not have outstanding indicators in resistance to wind load, but does not exclude the possibility of its use in high-rise buildings and structures due to its increased strength characteristics and lower cost compared to classical concrete.

References

1. "*Urban Planning Code of the Russian Federation*", December 29, 2004 N 190FZ (as amended on December 25, 2018).
2. SP 267.1325800.2016 *High-rise buildings and complexes. Construction requirements.*
3. N.M. Nikonov, Architecture and construction of Moscow, **1,** 35-40 (2007).
4. N.A.Chernukha, P.I.Gorelik, D.O. Lepeshkina, N.A. Chervova, SUZIS**, 9,** 5-9 (2015).
5. A.N. Birbraer, A. Y. Roleder, *Extreme impacts on structures. St. Petersburg*, Publishing House of the Polytechnic University, 370-389 (2009).
6. SP 20.13330.2016 *Load and impact.* Updated version of SNiP 2.01.07-85 * (GOST 27751-2014 *Reliability of building structures and foundations. The main provisions.*
7. SP 52-104-2006 *Steel-fiber concrete structures*.
8. Modern high-rise construction. Moscow, State Unitary Enterprise ITC Moscomarchitecture, 144-148 (2007).

9. I.V. Volkov, *Fiber-concrete - state and prospects of application in building structures*, Stroyprofil Magazine, **2**, 24-25 (2003).
10. S. V. Klyuev, Structural mechanics of engineering structures and structures, **4,** 71-75 (2011).
11. F.N. Rabinovich, *Composites based on dispersed reinforced concrete. Questions of theory and design, technologies, construction* (DIA, Moscow, 2004).
12. K.V. Talantova, Concrete and reinforced concrete, **5** (2003).