ENGINEER

international scientific journal

ISSUE 4, 2025 Vol. 3

E-ISSN
3030-3893

ISSN
3060-5172

SLIB.UZ
Scientific library of Uzbekistan

A bridge between science and innovation

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
Tashkent state transport university

ENGINEER

A bridge between science and innovation

E-ISSN: 3030-3893

ISSN: 3060-5172

VOLUME 3, ISSUE 4

DECEMBER, 2025

engineer.tstu.uz

TASHKENT STATE TRANSPORT UNIVERSITY

ENGINEER

INTERNATIONAL SCIENTIFIC JOURNAL
VOLUME 3, ISSUE 4 DECEMBER, 2025

Founder of the international scientific journal “Engineer” – Tashkent State Transport University, 100167, Republic of Uzbekistan, Tashkent, Temiryoʻlchilar str., 1, office: 465, e-mail: publication@tstu.uz.

The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

The journal is published 4 times a year and contains publications in the following main areas:

- Engineering;
- General Engineering;
- Aerospace Engineering;
- Automotive Engineering;
- Civil and Structural Engineering;
- Computational Mechanics;
- Control and Systems Engineering;
- Electrical and Electronic Engineering;
- Industrial and Manufacturing Engineering;
- Mechanical Engineering;
- Mechanics of Materials;
- Safety, Risk, Reliability and Quality;
- Media Technology;
- Building and Construction;
- Architecture.

Tashkent State Transport University had the opportunity to publish the international scientific journal “Engineer” based on the **Certificate No. 1183** of the Information and Mass Communications Agency under the Administration of the President of the Republic of Uzbekistan. **E-ISSN: 3030-3893, ISSN: 3060-5172.** Articles in the journal are published in English language.

Theoretical investigation of fiber-reinforced concrete beams dispersely reinforced with basalt and steel fibers

S.A. Kholmirzaev[1][a], A.R. Akhmedov[1][b], A.Sh. Martazaev[1][c], I.Kh. Egamberdiev[1][d]
[1]Namangan State Technical University, Namangan, Uzbekistan

Abstract: In this study, the maximum flexural load-bearing capacity of steel and basalt fiber-reinforced concrete beams was investigated through theoretical calculations. The ultimate bending moments of beams reinforced with different proportions of steel and basalt fiber mixtures were analyzed in detail. The theoretical results showed that the beam reinforced with steel fibers demonstrated the highest ultimate bending moment, confirming it as the most efficient option in terms of load-bearing capacity. At the same time, hybrid fiber-reinforced beams provided an optimal balance between load capacity and deformation resistance. The findings indicate that the proportion and dispersion of fibers have a significant influence on the mechanical behavior of beams under bending, and theoretically confirm the potential for designing and optimizing new types of fiber-reinforced concrete structures using a combination of steel and basalt fibers.

Keywords: fiber-reinforced concrete, steel fibers, basalt fibers, ultimate bending moment, dispersed reinforcement, flexural strength

1. Introduction

In modern construction, extensive research is being conducted to improve the reliability, long-term strength, and operational durability of load-bearing reinforced concrete structures [1]. Traditional reinforced concrete elements, particularly beams subjected to bending, tend to lose their initial strength characteristics under external loads due to increasing deformations and the formation and propagation of cracks [2]. Early crack formation not only limits the load-bearing capacity of the structure but also poses a serious threat to its overall reliability, service life, and seismic resistance [3]. Therefore, improving the crack resistance of concrete, enhancing its energy absorption capacity, and stabilizing deformations have become some of the most urgent issues in contemporary construction science [4]. Dispersed reinforcement of the concrete matrix using various fibers is considered one of the most promising solutions to this problem. As a result of dispersed reinforcement, a micro-reinforcement system is formed within the material, which redistributes internal stresses under load, delays crack initiation and propagation, and significantly increases the crack resistance of the structure [5]. In this regard, the combined use of basalt and steel fibers has attracted considerable scientific interest due to its potential for higher efficiency.

Steel fibers, owing to their high elastic modulus, high tensile strength, and excellent energy absorption capacity under loading, improve the plastic behavior of beams at the final stage of bending [6]. Basalt fibers, on the other hand, are distinguished by their corrosion resistance, high thermal stability, low water absorption, and environmental safety. Their combined application can enhance not only the strength and deformation characteristics of concrete but also its long-term performance. However, the interaction of these two fiber types, the effect of their proportion and dispersion, and their mechanisms of influence on the concrete matrix have not yet been sufficiently studied [7]. In particular, scientific sources on the theoretical modeling of bending behavior, crack resistance, load-bearing capacity at ultimate limit states, and stress–strain behavior of fiber-reinforced concrete beams strengthened with hybrid basalt–steel fibers are still limited [8]. Due to the variability of experimental results, the need for developing theoretical foundations and mathematical models is becoming increasingly evident [9].

The primary objective of this study is to theoretically analyze the crack resistance, stress–strain behavior, and flexural performance of fiber-reinforced concrete beams dispersedly reinforced with basalt and steel fibers. The research focuses on determining the influence of fiber content, distribution ratio, and geometric parameters on the crack resistance of the structure, as well as providing mathematical justification for beam performance under limit states. The theoretical results obtained in this study will contribute to identifying optimal fiber-reinforced concrete compositions, improving design standards, and expanding the practical application of highly crack-resistant beams in construction.

2. Methodology

In this study, the strength of fiber-reinforced concrete beams was evaluated based on theoretical calculations. For the analysis, each geometric variant of the beams was assumed to have the following dimensions: length – 1500 mm, width – 150 mm, and height – 200 mm. The combinations of fiber content considered in the theoretical calculations of fiber-reinforced concrete beams are presented in Table 1.

In the theoretical calculations, fibers were considered as reinforcing elements influencing the mechanical properties of concrete. The performance of fiber-reinforced concrete is evaluated based on the following parameters:

- Flexural strength of the beam;
- Moment of inertia and the equivalent modulus of the cross section;

[a] https://orcid.org/0009-0006-5117-0159
[b] https://orcid.org/0009-0001-1934-8694
[c] https://orcid.org/0000-0002-0799-8139
[d] https://orcid.org/0009-0006-9229-8116

https://doi.org/10.56143/3030-3893-2025-4-53-55 A bridge between science and innovation

- Tensile efficiency of concrete depending on the type of fiber;
- Variable modulus of elasticity and post-cracking behavior depending on the fiber ratio and total content.

Table 1

Fiber content combinations considered in the theoretical analysis of fiber-reinforced concrete beams

№	Series	Total fiber content in concrete, %	Basalt fiber content, %	Steel fiber content, %
1	BO	0	0	0
2	BP100B0	0.2	0	100
3	BP75B25	0.2	25	75
4	BP50B50	0.2	50	50
5	BP25B75	0.2	75	25
6	BP0B100	0.2	100	0

In the theoretical analysis, the strength parameters of the reinforcement and concrete were adopted based on the results of experimental studies conducted under laboratory conditions. The actual values of the concrete compressive strength, modulus of elasticity, and tensile strength of the reinforcement were incorporated into the theoretical model. As a result, the parameters used in the calculations fully reflected the real physical and mechanical properties of the materials.

Determining the ultimate load-bearing capacity of rectangular fiber-reinforced concrete beams is one of the main directions of the theoretical analysis, taking into account the residual tensile resistance of the concrete and the contribution of hybrid fibers—basalt and steel. The tensile strength of fiber-reinforced concrete, R_{fbt}, changes significantly in the presence of steel and basalt fibers, as the fibers maintain the concrete's integrity even after crack formation. Therefore, in addition to conventional reinforced concrete formulas, the residual tensile resistance, R_{fbt3}, must also be considered when determining the maximum bending moment. In fiber-reinforced concrete beams, the maximum bending moment is determined based on the moment equilibrium equation as follows:

$$\sum_{i=1}^{n} M = 0$$

Here, the concrete in compression, the tensile reinforcement, the area of reinforcement in the compression zone A'_s, the tensile strength of concrete $R_{fbt,}$ the residual tensile resistance associated with hybrid fibers R_{fbt3}, the beam width b, the beam height h, and the height of the compression zone h are all taken into account. According to the theoretical analysis, the maximum bending moment is determined using the following expression:

$$M_{ult} = R_{fb} \cdot b \cdot x \cdot (h_0 - 0{,}5x) - R_{fbt3} \cdot b \cdot (h - x) \cdot \left(\frac{h-x}{2} - a\right) + R_{sc} \cdot A'_s(h_0 - a') \qquad (1)$$

Here:

R_{fbt} - Tensile strength of fiber-reinforced concrete,

R_{fbt3} - Residual tensile resistance under the action of hybrid (basalt + steel) fibers,

b - Beam width,

h - Beam height,

x - Height of the compression zone,

Rsc - Design compressive resistance of the reinforcement,

A'_s - Area of reinforcement in the compression zone.

These parameters directly influence the load-bearing capacity of the beam; therefore, fiber-reinforced concrete strengthened with hybrid fibers can be accurately evaluated using the described equation. When basalt and steel fibers are combined, the residual tensile resistance, crack initiation, and propagation significantly change. While steel fibers provide high tensile strength, basalt fibers slow down the spread of cracks. The combined effect of these two types of fibers enhances the residual strength of the concrete. Determining the height of the compression zone in fiber-reinforced concrete beams is also an integral part of the analysis, as this parameter defines the balance between the concrete in compression and the concrete in tension. The height of the compression zone is determined using the force equilibrium equation:

$$\sum_{k=1}^{n} F_{kx} = 0$$

$$x = \frac{R_s \cdot A_s - R_{sc} \cdot A'_s + R_{fbt3} \cdot b \cdot h}{(R_{fb} + R_{fbt3}) \cdot b} \qquad (2)$$

This expression is formulated in accordance with the mechanical properties of fiber-reinforced concrete with hybrid fibers, taking into account the residual tensile resistance. The combined action of basalt and steel fibers allows the concrete in the tensile zone to continue carrying part of the stresses even after cracks have formed. As a result, stress redistribution occurs, and the load-bearing capacity of the beam increases compared to conventional reinforced concrete structures. Steel fibers play a primary role in increasing the maximum bending moment due to their high tensile strength, while basalt fibers limit crack propagation and ensure deformation stability. Their combination significantly enhances the residual tensile resistance of the concrete and extends the elastic-plastic behavior up to the ultimate limit state. Theoretical calculations indicate that fiber-reinforced concrete beams strengthened with hybrid fibers exhibit higher compression zone height, greater residual tensile resistance in the tensile zone, and a higher maximum bending moment compared to other variants.

3. Results and Discussion

The maximum load-bearing capacity of fiber-reinforced concrete beams based on fiber content is presented in Table 2.

Table 2

Maximum load-bearing capacity of fiber-reinforced concrete beams

№	Series	Ultimate bending moment, kN·m
1	BO	14.58
2	BP100B0	18.64
3	BP75B25	18.29
4	BP50B50	17.50
5	BP25B75	17.21
6	BP0B100	16.89

According to the results, the steel fiber-reinforced concrete beam (BP100B0) exhibited the highest ultimate bending moment of 18.64 kN·m. In the hybrid fiber compositions, the maximum moments were 18.29 kN·m for the BP75B25 series, 17.50 kN·m for the BP50B50 series, and 17.21 kN·m for the BP25B75 series. The basalt fiber-reinforced beam (BP0B100) demonstrated a maximum load-bearing capacity of 16.89 kN·m. These results indicate that steel fibers are more effective in enhancing the flexural strength of the beams, while the inclusion of basalt fibers results in a slight reduction. At the same time, the load-bearing capacity of beams reinforced with a combination of steel and basalt fibers exceeds that of conventional reinforced concrete beams, confirming the practical applicability of this type of fiber-reinforced concrete structure in engineering practice.

The fiber ratio has a significant effect on the bending moment of the beam. Steel fibers, due to their high modulus of elasticity, increase the beam's ultimate bending moment. The maximum load-bearing capacity of fiber-reinforced concrete beams dispersedly reinforced with basalt and steel fibers is shown in Figure 1.

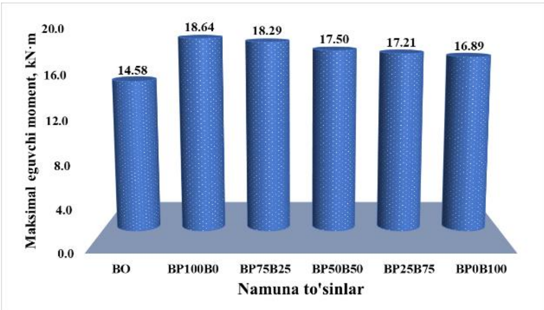

Fig. 1. Ultimate bending moment

4. Conclusion

In this study, the maximum load-bearing capacity of fiber-reinforced concrete beams with steel and basalt fibers was theoretically investigated. The experiments led to the following scientifically significant conclusions:

1. High efficiency of steel fiber-reinforced concrete:** The beam reinforced solely with steel fibers (BP100B0) exhibited the highest ultimate bending moment of 18.64 kN·m. This is attributed to the high modulus of elasticity and tensile capacity of steel fibers, which reduce deformation under load and enhance structural safety.

2. Optimal combinations with hybrid fibers: Beams reinforced with varying ratios of basalt and steel fibers (BP75B25, BP50B50, BP25B75) also demonstrated high load-bearing capacity, with ultimate moments ranging from 17.21 to 18.29 kN·m. This indicates that the load-enhancing properties of steel fibers are maintained even when combined with basalt fibers, while basalt fibers provide additional benefits by controlling cracking and increasing structural ductility.

3. Role of basalt fibers: The beam reinforced solely with basalt fibers (BP0B100) exhibited the lowest ultimate moment of 16.89 kN·m. Nevertheless, basalt fibers improve resistance to linear deformations through their high stiffness and dispersive distribution, which is crucial for structures subjected to heavy loads.

References

[1] Behbahani H., Nematollahi B., Farasatpour M. Steel fiber reinforced concrete: a review //Proceedings of the International Conference on Structural Engineering Construction and Management (ICSECM2011). – 2011. – C. 1-12.

[2] Martazaev A., Khakimov S. Dispersed reinforcement with basalt fibers and strength of fiber-reinforced concrete beams //AIP Conference Proceedings. – AIP Publishing LLC, 2025. – T. 3256. – №. 1. – C. 030011.

[3] Banthia N., Gupta R. Hybrid fiber reinforced concrete (HyFRC): fiber synergy in high strength matrices //Materials and structures. – 2004. – T. 37. – №. 10. – C. 707-716.

[4] Martazaev A., Orzimatova M., Xamdamova M. Determination of optimum quantity of silica fume for high-performance concrete //AIP Conference Proceedings. – AIP Publishing LLC, 2025. – T. 3256. – №. 1. – C. 030012.

[5] Dhanapal J., Jeyaprakash S. Mechanical properties of mixed steel fiber reinforced concrete with the combination of micro and macro steel fibers //Structural Concrete. – 2020. – T. 21. – №. 1. – C. 458-467.

[6] Razzakov S., Martazaev A. Mechanical properties of concrete reinforced with basalt fibers //E3S Web of Conferences. – EDP Sciences, 2023. – T. 401. – C. 05003.

[7] Klyuev S., Klyuev A., Vatin N. Fine-grained concrete with combined reinforcement by different types of fibers //MATEC web of conferences. – EDP Sciences, 2018. – T. 245. – C. 03006.

[8] Jurayevich R. S., Shukirillayevich M. A. Calculation of Strength of Fiber Reinforced Concrete Beams Using Abaqus Software //The Peerian Journal. – 2022. – T. 5. – C. 20-26.

[9] Teng S., Afroughsabet V., Ostertag C. P. Flexural behavior and durability properties of high performance hybrid-fiber-reinforced concrete //Construction and Building Materials. – 2018. – T. 182. – C. 504-515.

Information about the author

Sattar Kholmirzaev	Namangan State Technical University, "Department of Civil Engineering" Professor of the Department, Candidate of Technical Sciences E-mail: sattar59@mail.ru, Tel.: +998 97-217-86-06 https://orcid.org/0009-0006-5117-0159
Akmaljon Akhmedov	Namangan State Technical University, Doctoral Student, E-mail: axmedovakmalxon1@gmail.com Tel.: +99893-510-05-53 https://orcid.org/0009-0001-1934-8694
Abdurasul Martazaev	Namangan State Technical University, "Building and Construction" Department associate professor, PhD E-mail: abdurasul.mas@gmail.com Tel.: +99893-914-05-06 https://orcid.org/0000-0002-0799-8139
Ismoiljon Egamberdiev	Namangan State Technical University, Doctoral Student E-mail: egamberdiyevismoiljon490@gmail.com Tel.: +99893-949-69-89 https://orcid.org/0009-0006-9229-8116

https://doi.org/10.56143/3030-3893-2025-4-53-55

CONTEXT / MUNDARIJA