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BENDING WITH TORSION OF FIBER REINFORCED CONCRETE BEAM OF CIRCULAR CROSS SECTION

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Abstract. The article provides information about the tests of circle cross-section reinforced concrete beams made of high-strength steel-fiber concrete on combined torsion and bending. Given information contains the main results: a diagram of the cracks with an indication of their opening width, the values of support reactions at the moment of cracking and at the moment before destruction. It was found that as the load is applied in beams made of high-strength steel-reinforced concrete, in the case of several cracks at the first stage, there is one crack increases. The beams are modeled in the design complex and given description of the main design parameters. The results of the calculation are presented and a comparative analysis of the results obtained with the experiments results. It is noted that the adopted models in the computational complexes require the development of subroutines and refinement.

Keywords: reinforced concrete structures, combined bending and torsion, deformation, strength, circle cross section

КРУЧЕНИЕ С ИЗГИБОМ СТАЛЕФИБРОЖЕЛЕЗОБЕТОННОЙ БАЛКИ КРУГЛОГО СЕЧЕНИЯ

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Аннотация. В статье приведена информация о проведенных испытаний железобетонных балок круглого сечения из высокопрочного сталефибробетона при действии кручения с изгибом. Приведена информация по основным полученным результатам: схема трещин с указанием их ширины раскрытия, значения опорных реакций в момент образования трещин и в момент, предшествующий разрушению образца. Установлено, что по мере приложения нагрузки в балках из высокопрочного сталефибробетона увеличивается в основном одна трещина, даже в случае возникновения нескольких трещин на первом этапе. Произведено моделирование балок в расчетном комплексе с описанием основных расчетных предпосылок. Приведены результаты расчета и выполнен сравнительный анализ полученных результатов с результатами проведенных экспериментов. Отмечено, что принятые модели в расчетных комплексах требуют разработки подпрограмм и уточнения.

Ключевые слова: железобетон, кручение с изгибом, деформации, прочность, квадратное сечение

INTRODUCTION

The designed elements of reinforced concrete structures, especially unique buildings and structures that operate in conditions of a complex stressed state - torsion with bending. A separate group of elements can be distinguished (beams with consoles, edge beams, stiffening cores of high-rise buildings, spatial frame structures, etc.) in which torsion plays a primary role in the work.

Work in the field of investigation of the torsion of reinforced concrete structures was carried out and is being carried out by many specialists, both Russian and foreign: V.M. Bondarenko, P.F. Vakhnenko, A.I. Demyanov, N.I. Karpenko, V.I. Kolchunov, V.I., A.M. Kuzmenko, V.I. Morozov, V.I. Travush, A. Bishara, H. Gesund, E. Rausch, T.T.C. Hsu et al. [1-15]. At the same time, only individual authors have dealt with the issue of the operation of structures with the combined action of torsion and bending, and the issue of the operation of reinforced concrete structures made of high-strength fiber-reinforced concrete is at the initial stage.

Despite the fact that technological progress and existing needs require the use of new materials, regulatory documents cannot cover the entire range of emerging tasks, and the responsibility for the choice of both the design model and the obtained calculation results lies directly with the designer, who is faced with a difficult choice issue a calculation model that allows you to properly reflect the actual performance of the structures. In most cases, the solution to the problem arises comes down to assumptions, due to the lack of results of the conducted field experiments.

Considering the above, the development of a methodology for calculating reinforced concrete structures made of high-strength steel-fiber reinforced concrete in torsion with bending, taking into account the occurrence of cracks, is an urgent task. In this case, the refinement of the main design parameters (deflections and angles of rotation of sections, the scheme of cracks and their opening width, the moment of crack formation) adopted in the design model should be carried out on the basis of comparing the calculation results with the results of the experiments performed.

RESULTS AND DISCUSSION

A number of experiments were carried out to study the work of reinforced concrete beams of a circular cross-section on the joint action of bending with torsion to determine the actual bearing capacity.

For the study, beams of circular cross-section with a diameter of 20 cm and a length of 1.2 m were made. The beams were made of steel fiber reinforced concrete B130 with steel fiber 13 mm long, 0.3 mm in diameter and a temporary resistance of at least 1200 MPa.

Reinforcement of beams is made in the form of welded frames with longitudinal and transverse reinforcement A240 Ø6 mm. The longitudinal reinforcement is provided with eight rods, the transverse reinforcement is located in 100 mm increments. To be able to transmit torque, embedded parts were provided at the ends of the beams.

During the experiment, a beam with 720 mm long consoles welded to the embedded parts installed at the ends was installed by the middle part on a support, and a vertical force was transmitted to the consoles through the traverse (Fig. 1). The loading was carried out in stages - in steps equal to 10% of the cracking load. The fixation of instrument readings (indicators of deflection meters) was carried out at each stage before and after exposure.

In the course of the experiments, the moment of occurrence of cracks, as well as the moment of destruction of the samples, were recorded with the determination of the corresponding forces (Fig. 2).

According to the results of the experiment, data on the complex stress-strain state during bending with torsion in the studied areas of the beams were obtained and the main parameters were determined:

- the experimental value of the support reaction at the time of the formation of spatial cracks was 12.5 kN, with the destruction of reinforced concrete structures - 17.5 kN;
- coordinates of the formation of spatial cracks;
- deflections of the consoles and, accordingly, the angles of rotation;
- change in the length of the projections of spatial cracks, depending on the increase in the loading steps;

Based on the analysis results, a fracture pattern was drawn up. A diagram of cracks with indication of their numbers and opening width is shown in Fig. 3.

During the experiments, it was noted that as the load is applied in the beams made of high-strength steel-fiber reinforced concrete, mainly one crack increases, even if several cracks appear at the first stage.

The formation of a single spatial crack in the considered samples led to a rapid opening of this crack, a significant increase in deformations, with a corresponding increase in deflections and angles of rotation.

For comparison with the results of the experiments carried out, the beam was modeled in the ANSYS environment and the calculation was performed.

As a design model, a beam with consoles was considered, which has a support in the middle. All dimensions are shown in the figure.

The formation of a geometric model in the software package was carried out on the basis of data on the samples used in the experiments. The geometric model is a concrete model of a circular beam with a diameter of 200 mm.

Inside the concrete is a reinforcing cage, consisting of longitudinal reinforcement - located at a distance of 25 mm from the edge to the center of the rods, and transverse reinforcement, located with a step of 100 mm.

Consoles in the form of elements of rectangular section 50x200 mm and length 720 mm were rigidly attached to the geometric models of concrete and reinforcement.

The next stage of computational modeling was the assignment of element types and the construction of a finite element mesh.

The concrete of the beam is represented by solid finite elements of the SOLID65 type, the beam reinforcement was modeled with bar finite elements of the BEAM188 type. The consoles and the supporting part of the beam are modeled with solid elements of the SOLID185 type.

Volumetric finite elements of the SOLID65 type are designed to simulate elements that allow cracking during tension, and they also allow the possibility of material destruction during compression. Taking into account the fact that, according to the results of the experiments, destruction occurs after the tensile reinforcement reaches the yield point, for the purposes of the research, the possibility of concrete destruction during compression was not considered (the option of destruction of compressed concrete was not used).

Additionally, shear transfer coefficients (0.7) are introduced, and the ultimate tensile stresses (9.6 MPa) and ultimate compressive stresses (132.5 MPa) are limited. The range of shear transfer ratio is set from 0 to 1, where 0 corresponds to no transfer of shear (smooth crack), and 1 corresponds to full transfer of shear.

For concrete modeling in the ANSYS environment, a combination of the following materials is adopted: Linear Isotropic, Multilinear Isotropic and Concrete. Linear Isotropic is used to set the initial modulus of elasticity and Poisson's ratio of concrete. The Multilinear Isotropic material implies the creation of a curvilinear diagram by multilinear approximation. Concrete material provides for the formation of cracks when the principal stresses exceed the specified tensile strength, as well as taking into account the triaxial stress state.

The physical and mechanical characteristics of concrete were determined from the results of statistical processing of tests of cubes and prisms. The results are shown in Table 1.

The modulus of elasticity, ultimate compressive strength and tensile strength in bending for concrete in this design study were taken in accordance with the data obtained on the samples made from high-strength fiber-reinforced concrete: Eb = 48.4 GPa, Rb = 132.5 MPa, Rbt = 9.6 MPa.

The diagram of work for reinforcing steel A240 was taken as two-line with hardening in accordance with the recommendations of SP 63.13330. The ultimate tensile and compressive strength in the calculations was taken equal to 240 MPa.

The load was applied to the ends of the cantilevers in accordance with a certain design scheme, making it possible to obtain a complex stress-strain state in the beam during torsion with bending.

Figure 1. Beam testing process

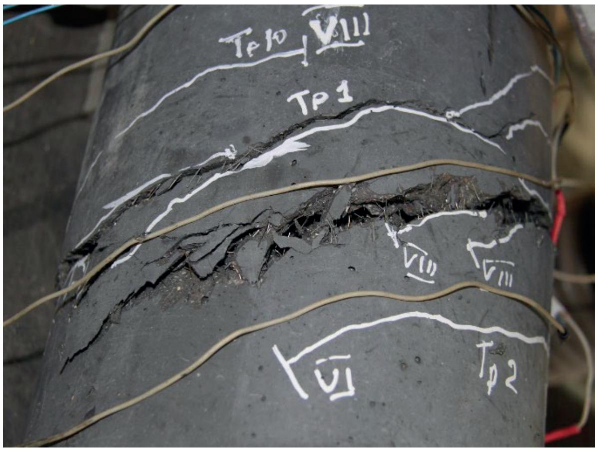

Figure 2. Crack in the beam at the time of destruction

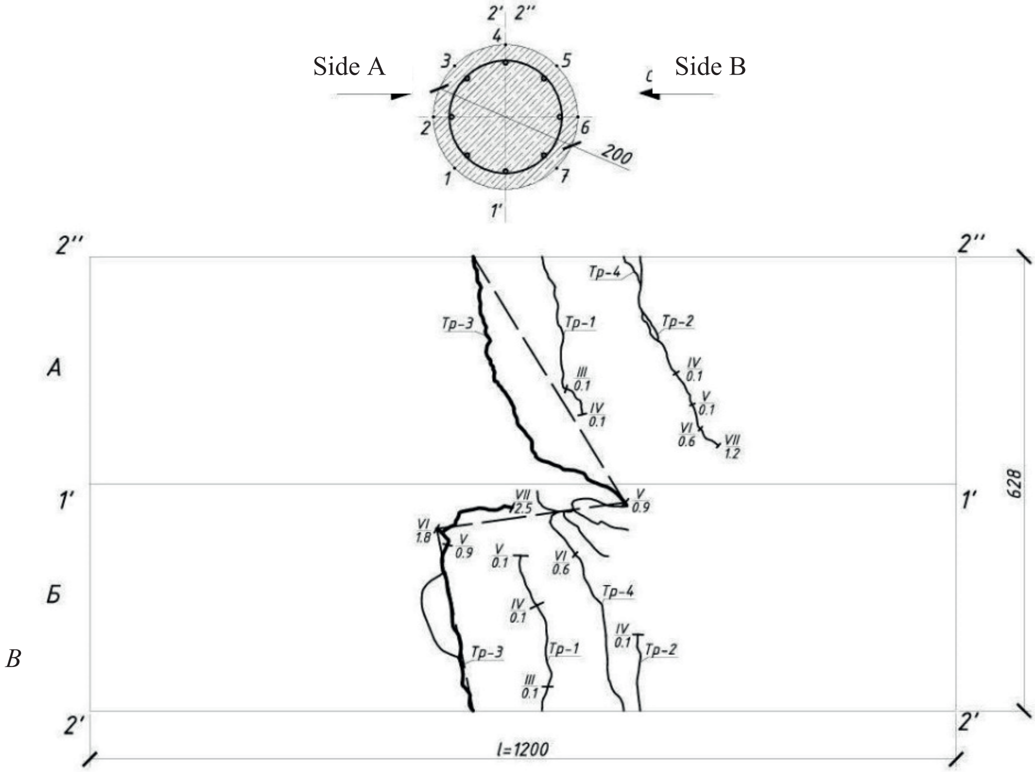

Figure 3. Crack diagram

Table 1. Physical and mechanical characteristics of concrete

No	Concrete type	Прочность бетона в 28 сут., МПа				Elastic modulus, GPa		Actual class of concrete at a coefficient of variation of 10%
		R	R_b	R_{bt}	R_{tt}	E_b	E_{dyn}	
Ultra high strength concrete								
1.	Fiber concrete	152.6	132.5	9.6	22.6	48.4	54.6	B134

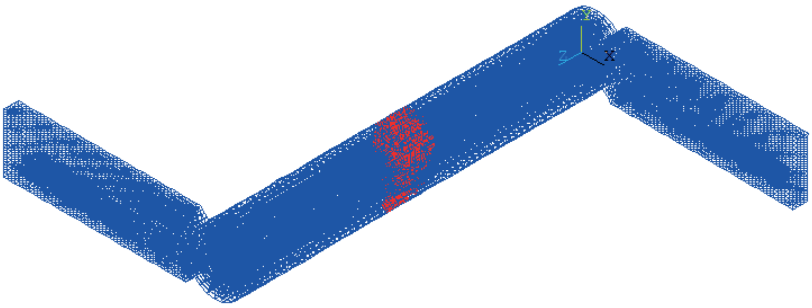

Figure 4. Arrangement of cracks in a beam

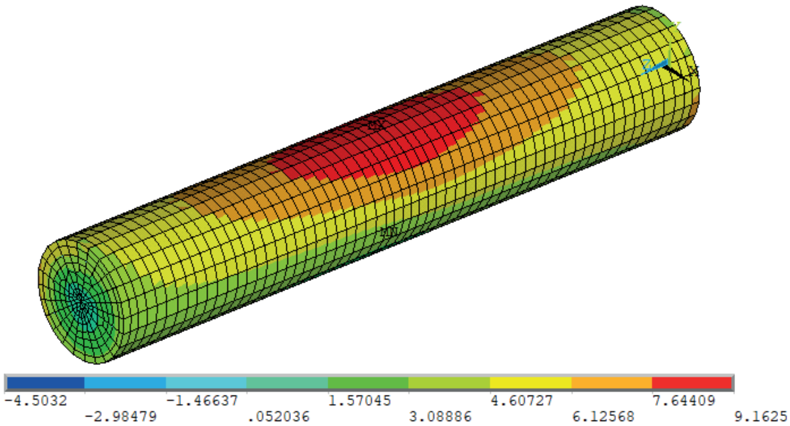

Figure 5. Principal stresses in concrete prior to cracking

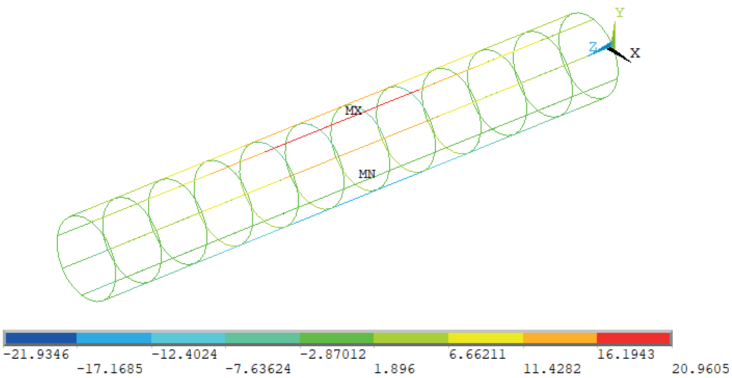

Figure 6. Reinforcement stresses preceding the moment of cracking in concrete

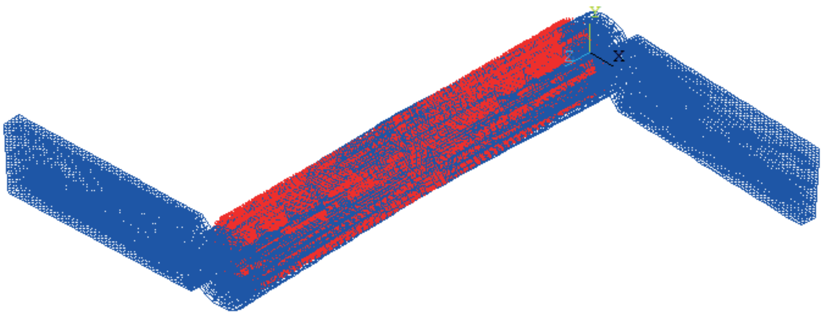

Figure 7. Arrangement of cracks in a beam

The loading of the model was carried out nonlinearly with the definition of an automatic step at the initial stages of 0.5 kN and a decrease in the step to 0.05 kN at the stage preceding the formation of cracks.
The fixing of the support platform of the beam was carried out by imposing displacement restrictions in three directions along the lower surface of the platform.
Based on the calculation results, the stresses in the beam elements, deformed schemes, crack locations at various loading stages were obtained, and the moment of crack initiation was determined.
The moment of crack initiation was determined at step 21 and corresponds to loads on the beam cantilevers of 9.8 kN. The crack locations at this moment are shown in Fig. 5.
Tensile stresses in concrete, preceding the moment of cracking, were 9.16 MPa (Fig. 5). Tensile stresses in reinforcement - 21 MPa (Fig. 6).
The displacement of the ends of the cantilevers at the moment of cracking was 1.4 mm.
The moment of failure of the beam is determined at step 149 and corresponds to loads on the beam cantilevers of 16.2 kN. The crack locations at this moment are shown in Fig. 7.
Tensile stresses in reinforcement in almost all longitudinal bars amounted to - 272 MPa.
The displacements of the ends of the consoles at this moment were 48 mm.
Based on the results of the calculations, the values of the forces transmitted to the beams' consoles at the moments of cracking and at the moment of destruction were determined. At the same time, the forces obtained at the time of cracking in the beam during the calculation (9.8 kN) are slightly lower than the values obtained as a result of the experiment (12.5 kN). Also, the efforts obtained at the moment of fracture in the calculation (16.2 kN) slightly differ from the experimental data (17.5 kN).
The deformed beam pattern is determined by significant displacements of the cantilevers, which is due to the rotation of the section with the formation of a plastic hinge (due to the reinforcement reaching the yield point) in the center of the beam, which corresponds to the moment of cracking and was 9.8 kN.
The actual destruction of the beam during the experiment, similar to the calculation, did not occur quickly, with the formation of plastic deformations and the absence of brittle fracture.
Also, one of the distinctive features revealed during the experiments was the growth of one main crack, however, according to the results of the calculations, a network of cracks is formed, which, as the load increases, captures an ever larger surface of the considered beam.
Such a significant difference requires the development of subroutines for the possibility of correcting the computational model and bringing the results obtained in line with the experimental data.

CONCLUSIONS

1. During the experiments, it was noted that as the load is applied in the beams made of high-strength steel-fiber reinforced concrete, mainly one crack increases, even if several cracks appear at the first stage.
2. The formation of a single spatial crack in the considered samples led to a rapid opening of this crack, a significant increase in deformations, with a corresponding increase in deflections and angles of rotation.
3. The ANSYS software package allows you to perform volumetric modeling of reinforced concrete elements, taking into account the reinforcement and the purpose of nonlinear diagrams of concrete and reinforcement work.
4. The ANSYS software package can be used to assess the performance of reinforced concrete elements, including to the stage of destruction.
5. The moment of cracking and the moment of fracture (transmitted force), obtained as a result of the calculation, differ slightly from the values obtained as a result of the experiments carried out.
6. In contrast to the experiment with the formation of one main crack, during the

calculation in the software package, a network of cracks is formed, which requires the development of subroutines.

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