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Forecasting the Strength of Structures Taking into Account the Nonlinearity of Deformation Based on Dispersed-Reinforced Concrete

Khamrakulov Ravshan Djabborovich, Mirzakobilov Norkuzi Khujakulovich, Zhabborov Atxam Ravshanovich, Sagatov Baxodir Uktamovich

Jizzakh Polytechnic Institute, 130100 Jizzakh, Uzbekistan

Abstract. *This article discusses the study of the strength of ordinary and dispersed reinforced concrete, taking into account the nonlinearity of deformation and the analysis of the mechanisms for the manifestation of interaction in cracks, in order to take into account the nonlinear properties of reinforced concrete in practice. Calculations, in addition to creating more complex programs, there is a need to pay attention to a more accurate assessment of the basic fundamental properties of reinforced concrete.*

Keywords: deformation, reinforced concrete, construction

1. Introduction

In modern construction, the main load-bearing structures are made of various types of concrete and reinforced concrete. They will retain their dominant positions in the long term and make up a significant proportion of the structures used in the design of structures for various purposes: bridges, flyovers, industrial and civil construction projects. Reinforcement increasing the bearing capacity leads to a significant complicated work condition of materials.

In practical calculations of the structure at the stage of operation without cracks, the effect of reinforcement on this connection is not significant, and the properties of reinforced concrete can be considered isotropic. After cracking, the anisotropy manifests itself quite significantly, especially in the presence of a shear force in a direction parallel to the orientation of the cracks. The most important is the development of new methods associated with the complication of structural forms, considering the nonlinearity of deformation with poorly studied problems of destruction and exhaustion of the bearing capacity of reinforced concrete structures [1, 2].

The large scale and complexity of new types of reinforced concrete structures erected in recent years entail an increase in uncertainty in assessing their reliability, and require a significant development of numerical methods for their calculation [3]. The rapid development of computer technology and electronics, as well as new methods, opens up broad prospects in this direction. Thus, for a wide class of construction, finite and boundary element methods (FEM, BEM) are effectively used, for which a large number of programs have been developed that mainly implement the linear elastic properties of materials [4, 5]. In order to take into account the non-linear properties of reinforced concrete in practical calculations, in addition to creating more complex programs, it becomes necessary to pay attention to a closer assessment of the fundamental, fundamental properties of reinforced concrete.

Dispersion-reinforced concrete is now experiencing major development in the building industry [6]. This is because despite all of its advantages, concrete and reinforced concrete have a number of drawbacks. Low crack resistance, which leads to the brittle fracture of buildings, is seen to be the most serious negative. The most hazardous concrete fracture is the brittle fracture because it can result in the sudden and gradual collapse of an entire building or structure [7].

Recently, scientific data aimed at further development of reinforced concrete mechanics methods and scientific development and experimental substantiation of new physical concepts and engineering methods for calculating reinforced concrete structures provide an adequate assessment of their work at all stages of loading. The developed set of models describing the behavior of reinforced concrete elements with cracks is based on the methods of fracture mechanics of structural-simulation, probabilistic-statistical and physical modeling [8, 9, 10, 11]. This allows you to create the necessary prerequisites for refining the calculations of reinforced concrete structures, based on the real pattern of displacements in the cracks of elements and the actual distribution of stresses and strains in sections with cracks. As a result of studying new features of the operation of reinforced concrete with cracks, the reliability of estimates of the stress-strain state of reinforced concrete structures increases, taking into account the nonlinearity of deformation through the use of theoretically justified models instead of the used partial empirical coefficients and dependencies [12].

Further improvement of the technical, economic and operational indicators of reinforced concrete structures will significantly accelerate scientific and technological progress in the construction industry. At the same time, it requires the development of more advanced and efficient methods and design of concrete and reinforced concrete elements aimed at the influence of the reserves of their bearing capacity, the maximum use of their real physical properties and behavioral characteristics under operational impacts of various nature. These issues are widely reflected in the current regulatory documents and their further practical implementation is associated with the development of new engineering methods of calculation, oriented and implemented on a computer and allowing, on the one hand, to take into account the increasing complexity and scale of the designed structures, and on the other hand, to more accurately take into account features of nonlinear deformation of the material [13].

When assessing the stress-strain state of the concrete structure under load and temperature-humidity effects, various physical models of the concrete structure have become widespread. Basically, they are based on ideas about it as a two-component material [14]. One of the first models with an oriented structure of this kind for concretes was compiled by A. Branzaegoi on the basis of a generalization of experiments with marble, which showed the non-isotropy of the properties of a crystalline substance relative to the crystalline axis. The constructed model took into account the influence of two types of fracture: intercrystalline due to slip and intracrystalline due to cracks. Constant constants depending on the ratio of longitudinal and transverse strains on the external load are the modulus of elasticity, shear strength and the angle of internal friction. Good agreement between the theoretical and experimental curves for bodies like concrete was observed in the initial stages of loading.

Determination of deformability and crack resistance of concrete and reinforced concrete structures is based on conventional heavy concrete. New methods, new manufacturing technologies are being developed, huge volumes of reinforced concrete structures are used, but many issues related to the assessment of their rigidity, bearing capacity and reliability still remain unresolved [15, 16, 17].

In real operating conditions, even at relatively low levels of loads, cracks of various orientations and depths develop in concrete, anisotropy of deformation inhomogeneity appears in structures. All features of material deformation can be studied only within the framework of mathematical models obtained by methods of solid mechanics of a deformable body.

The use of a wide range of different concretes and a variety of factors affecting their properties, as well as the impact of complex loading conditions used in each specific case, calculation methods using systems of imperial formulas and coefficients that do not have a common basis cease to meet modern design requirements. It becomes impossible to comprehend adequately reflect the main important regularities in the process of deformation of cracking and destruction of the structure. The physical phenomena accompanying the weight of the period present in the destruction of the structure need further in-depth studies [18]. It is necessary to develop an understanding of the essence of the destruction of the material of construction developing in time and having its own characteristic stages. The resistance of concrete and reinforced concrete is still traditionally considered without taking into account the special role and significance of micro- and macrocracks, which largely determine the behavior of the structure. This determines the relevance of research.

The purpose and objectives of the study is to predict the strength of concrete, taking into account the nonlinearity of deformation and the analysis of the mechanisms for the manifestation of interaction in cracks and the transmission of forces through cracks, in order to take into account the nonlinear properties of reinforced concrete in practical calculations, in addition to creating more complex programs, it becomes necessary to pay attention to a more accurate assessment of the fundamental fundamental properties of concrete and reinforced concrete.

2. Materials and Methods

The calculation methods used in the normative documents of different countries are based mainly on the analysis of the balance of external loads and internal limit forces in inclined sections of elements. In some cases, the methods were replaced or supplemented by other approaches based on statistical multivariate analysis or using different models of analogy. Such models are illustrative and widely accepted by various researchers. Thus, a modification of the method of proprietary analogy, proposed by Mersch at the beginning of the 20th century, is the basis of the modern EKB-FIP recommendations for the calculation of reinforced concrete beams for shear. Some shortcomings of static methods and models - analogies (idealization of calculation schemes, low information content, lack of physical ideas about the mechanisms of behavior, etc.) can be easily eliminated when combined with the limit equilibrium method. This will avoid some difficulties in its implementation associated with the assessment of stresses in concrete and reinforcement and the determination of internal forces in the element, including the stage close to failure.

Considering the forces of engagement in cracks makes it possible to increase the degree of reliability in assessing the behavior of reinforced concrete beams with cracks that experience the action of transverse forces. As a result of ongoing research and testing, the structure of a material such as concrete will be established can be considered as a complex hierarchical system. In this regard, the following will be predicted: - the influence of structural defects and the properties of its components on the stress-strain state and cracking in the material; - based on the analysis of the main theories and models of the strength of concrete, the expediency of using the methods and tasks of structural simulation modeling based on the solutions and prerequisites of the mechanics of fracture of elastic-brittle composite materials similar to concrete is shown; - a structural simulation mathematical model of cracking and destruction of concrete under uniaxial compression is proposed, showing the conditions for the appearance, merging and development of cracks in the material, as well as taking into account the redistribution of stresses between the components of its structures. - the influence of the material structure on the crack resistance characteristics of concrete and new experimental data will be obtained on the effect of the type, structure and composition of concrete on the critical stress intensity factor for various types of stress state and varying initial crack length, etc. Contact interaction in shear cracks manifests itself in the form of a complex mechanism of engagement of their faces and cannot be expressed by a simple friction law.

The technique for experimentally determining the dependence of the tangential forces of engagement in a crack on the corresponding displacements of its edges makes it possible to estimate the stiffness and strength of the contact interaction in a crack; - corresponding expressions will be obtained for estimating the shear stiffness and ultimate resistance of contact interaction in a crack. It is revealed that the ultimate shear resistance can be expressed on the basis of a strength criterion or using a modified criterion with constants established for each type of concrete that satisfy the test results; - implementation of the obtained structural simulation model of contact interaction in a crack and the possibility of its effective use in nonlinear calculations of the stress-strain state of structures by numerical methods.

Metal fibrous monolith is used in reinforced concrete structures and prefabricated structures. Although the typical sizes of metal fibers are heterogeneous and vary, metal fibers of various shapes are mainly used: diameter 0.2 ... 1.2 mm and length 5 ... 12 cm. Thus, it has been experimentally proven that the diameter of the metal fiber used determines the cracks in the composite: d-0.3 has the characteristics of local cracks when using cracked metal fibers, their size does not exceed 1-3 mm, increasing, the diameter of the fibers up to 0.9 mm is the same [19].

Depending on the degree of adhesion of the metal in the cement mixture, various configurations are developed to increase the adhesion of metal fibers. Especially hook, wavy, etc.

It is known that in recent years, high-strength concrete and reinforced concrete structures have been used in hydraulic structures and road construction in the country. Dispersed reinforcement with metal shavings is widely used, especially in the production of fine-grained concrete [20].

To increase the crack resistance, elongation strength and abrasion resistance of fine-grained concrete, fibrous fibers are added to the structure, which act as dispersed reinforcement.

The acicular structure of the reinforced particles binds the cement and sand particles together, forming a strong framework between fine aggregates. Thus, the size of a firmly glued frame practically does not change and does not lose strength.

Fibers are especially effective in reinforcing thin-walled structures made of fine-grained reinforced concrete. This allows you to save on fittings made of precious metals, etc. Metal fibers can be used directly in the construction of castings and in the production of precast concrete structures.

Metal fiber is added on average 70 ... 200 kg per 1 m^3 of concrete mixture (3 ... 9% by weight). When concrete is dispersed-reinforced with metal fibers, its degradation is slow. Cracks in concrete occur at much higher strains than in conventional concrete. The fibers form the inner frame of the concrete structure, providing its tensile strength [21].

Fine-grained fiber concretes have higher tensile strength, bending strength, shear strength, cracking strength, fatigue strength, etc. Than ordinary heavy concrete or reinforced concrete with metal reinforcement, it is characterized by high properties, such as strength, crack resistance, waterproofing, cold resistance, heat resistance and fire resistance. Before the concrete is poured directly, the fiber is mixed, i.e. the mixture is produced directly or indirectly in a concrete plant, which is technologically optimal [22].

3. Results and Discussions

The processes of preparation and testing of samples of simple and fine-grained glass fiber with dispersed reinforcement were carried out in the accredited laboratory "Testing of building products" of the Jizzakh Polytechnic Institute. Physical and mechanical properties of Portland cement is shown in Table 1, which is part of the Jizzakh Cement company, showed its physical and mechanical properties.

Table 1. Physical and mechanical properties of Portland cement

Degree of softness %	Water requirement %	Setting time h-min.		Strength MPa		Density g/sm^3		Fineness of grinding, sm^2/g
		Start min.	End of the hour	When bending	When compressed	Actual	Bulk	
9.4	25.5	45	2	5.45	39.3	2.95	1.75	3200

The main properties and granular composition of the used quartz sand are shown in Table 2.

Table 2. Grain composition of quartz sand

Number of residues on the grid	Mesh dimensions, mm						Size modulus
	2.5	1.25	0.63	0.315	0.16	Less than 0.16	
Private remains	1.7	11.5	37	32	21.8	5	2.08
Full balance	1.7	13.2	50.2	82.2	104	100	

Actual density, g/cm^3	Bulk kg/m^3	Porosity, %	Humidity W, %	Water demand, C %	Specific area Sn, m^2/kg	Average size T	Total balance in the grid, %	Size modulus, Mcr	The amount of harmful impurities and components,%
2.50	1460	42	6.4	10	53.64	0.14	50.2	2.08	2.25

The strength of concrete, usually used for hydraulic structures and road surfaces, should be at least 20, 25 MPa, depending on the category of the road, and frost resistance should be at least MP3150. The coefficient of variation of the sand size modulus should not exceed 10% for concretes used for hydraulic structures. Therefore, it is recommended to add waste fibers to achieve the desired strength without changing the cement consumption. The total residual amount of crushed stone was determined by the following formula and it main characteristics is shown in Table 3:

$$A_i = a_{20} + ..a$$

$$A_{20} = 36\%; A_{10} = 80\%; A_5 = 100\%;$$

The porosity of crushed stone was determined by the following formula:
The moisture content of crushed stone was determined as follows:

$$W_n = \left(\frac{m_b - m_c}{m_c}\right) * 100\% = \frac{2400 - 2350}{2350} * 100 = 2.13\%$$

Table 3. The main characteristics of crushed stone

Bulk g/m^3	Actual g/m^3	Porosity %	Humidity %Wn	Number of field residues				According to GOST
				40	20	10	5	Rubble
1540	2680	38	2.13	0	36	80	95	Suitable for use

Water for concrete. Potable water is usually used to prepare concrete mix. In addition, for concrete mixtures, you can use running water with a hydrogen index pH> 4 and solutions of various salts that do not exceed the required standards. The amount of salts in water should not exceed 5000 mg/l [21]. The most important element of technology that determines the efficiency of the fiber is the choice of metal fiber [23, 24, 25, 26]. At present, the production of metal fibers (20 types) has been mastered. According to one point of view, the parameters of the metal fiber and its mechanical properties are given in Tables 4.

Table 4. Dimensions of metal fibers, mm

Steel fiber	60/01.0	60/0.8	50/1.0	50/0.8	30/0.8	30/0.6	30/0.5
Length mm	60.0 ±5	60.0 + 5.0	50 ±5.0	50.015.0	30.0 + 3.0	30.013.0	30.013.0
Diameter	1.010.1	0.810.05	1.010.1	0.8 + 0.05	0.8 + 0.05	0.6 + 0.05	0.510.05

Distance	50 + 2.0	50.0 + 2.0	40.0 + 2.0	40.0 + 2.0	20.0 + 1.0	20.011.0	20.011.0
Hook length	5011.0	5.0 + 1.0	5.0+ 1.0	5.011.0	5.011.0	5.011.0	5.011.0
Hook height	2.510.4	2.5 + 0.4	2.510.4	2.510.4	2.2 + 0.4	2.210.4	2.210.4

Table 5. Comparisons of the obtained results

Fiber concrete samples	Requirement according to the rules	Obtained average values
		kg/sm^2
Concrete with 3% fiber (cube 100x100x100mm)	B-15, M200	226.03
Concrete with 5% fiber (cube 100x100x100mm)	B-15, M200	249.25
Concrete with 7% fiber (cube 100x100x100mm)	B-15, M200	250.08

Cubic samples are 28-day strength indicators.

Comparative characteristics of dispersed reinforced fine-grained concrete with additions of 2-3%, 5%, 7% fiber is shown in Table 5. Of these, 5% fiber-reinforced concrete was chosen.

The strength of heavy concrete after 7, 28, 60 and 90 days is 7.9, respectively; 14.9; 15.1; and 15.16 MPa. At the same time, the strength of heavy concrete on days 7, 28, 60 and 90 with the addition of 5% fiber to the same composition (second composition) was 9.3, respectively; 18.0; 18.01 and 18.49 MPa, respectively. That is, the strength of concrete with the addition of 5% fiber increases by 22 ... 25% compared to conventional concrete. This means that fiberglass can be more effective, especially for heavy concretes, when used as particulate reinforcement. The structure of dispersed reinforced fine-grained concrete contains shrinkage and technological micro and macropores, voids, microcracks and microchannels, which adversely affect the strength, density and performance properties of concrete. Concrete based on dense aggregates has a porosity of 5-10%. Partial or complete filling of this porosity with fibrous fibers improves the properties of the concrete.

The ""« class» of concrete is used in calculations as a characteristic of the quality of concrete in terms of strength. The class of concrete is the ability to withstand the compressive strength, determined on the 28th day, with 95% coverage of a concrete cube with dimensions of 15x15x15 cm at the edges. The difference between the brand and brand of concrete is characterized by providing an acceptable resistance value. The provision of resistance for this brand of concrete is 50% (i.e., the average value of resistance is acceptable). For the class of concrete, this provision is 95%. The relationship between grade and grade of concrete is expressed by the following formula:

$$B = R_m\ (1\text{-}1.64\text{-}Cv)$$

Cv =0.135 coefficient of variation.

Based on the experimental results obtained above, we determine the brand of concrete (28-day) for the resulting compositions. Tab. 3.1-3.2 shows that the 28-day strength of 10x10 cm cubes is Rm1 = 14.9 MPa for the first composition; Rm2 = 18.1 MPa for the second content; The strengths of the compositions (through the transition coefficient a = 0.95) are as follows:

$$R_m = 14.9 \cdot 0.95 = 14.1\ MPa,\ R_{m2} = 18.1 \cdot 0.95 = 17.9\ MPa$$

We determine the classes of concrete for the two resulting compositions. To do this, determine the root-mean-square tensile strength of concrete d and the values of the coefficient of variability of strength Cv. We determine the classes of concrete for the two resulting compositions. To do this, determine the root-mean-square tensile strength of concrete d and the values of the coefficient of variability of strength Cv (Table 6).

According to Table 6 below, the compressive strength of concrete for the first composition is 14.76 MPa. So, this class corresponds to BI5. In terms of strength, the second composition corresponds to concrete with a class of 18.1 MPa, B20.

Table 6. Strength of cubic concrete samples

T/R №	Sample dimensions sm	Force impact area, A, sm^2	Destructive force P, Kn	Strength of individual samples Rv, MPa	Average strength of specimens, Rv, MPa
1 Ordinary concrete					
1	10.1x10.2	103.02	297.73	21.4	
2	10.1x9.8	98.98	284.20 -	20.2	20.6

3	10.1x10.2	103.2	305.99	21.2	
2 Ordinary concrete with fiber					
1	10 x 10	100	304.74	30.4	
2	10.1x10	101	235.46	23.3	26.8
3	9.8x10.2	99.96	268.53	26.9	
3. Fine-grained concrete with fiber					
1	10.2x10.2	104.6	263.6	25.2	
2	10x9.9	99	249.5	25.2	25.1
3	10.3x10.2	105.6	261.9	24.8	

According to Table 7 below The prismatic strength of ordinary heavy concrete after 28, 60 and 90 days is 15.5; 19.3 and 19.7 MPa, respectively. The strength of fine-grained concrete of a similar composition with 3% dispersed reinforcement based on fiber is 23.7; Were 26.1 and 27.7 MPa, respectively. That is, it was noticed that the increase in strength was up to 20%;

Table 7. The prismatic strength of ordinary heavy concrete.

№	Sample sizes, cm	Force impact area A, sm^2	Breaking force P, kN	Strength of individual samples Rv, MPa	Average strength of samples Rv, MPa
After 28 days					
1	9,3x10,1	93,9	259,24	27,6	
2	10,1x9,85	99,5	206,74	20,7	23,7
3	10,1x10,1	102,5	224,58	« 23	
After 60 days					
1	10,1x10,5	106	271,32	25,5	
2	10,1x10,15	102,5	239,12	23,2	26,1
3	10,1x10,35	104,5	309,25	29,5	
After 90 days					
1	10,2x10,43	106,3	280,29	26,3	
2	10,2x10,25	104,6	285,44	27,2	27,7
3	10,3x10,35	106,6	316,47	29,6	

Fiberglass concrete provides the basis for the long-term conservation of hydraulic structures and water pipes in full.

Dispersed reinforcement with metal shavings demonstrates a targeted control of the formation, strength of the fine-grained concrete system, which makes it possible to obtain fiber concretes with high physical and mechanical properties.

The use of fiber-reinforced concrete in the construction of hydraulic structures and airfield pavements increases their durability, provides strength and durability, opens up the possibility of widespread use of industrial waste (secondary scrap metal). Fiber concrete has high tensile and bending strength, which ensures the original shape of the structure without deformation.

4. Conclusions

Fiber concrete structures retain their appearance for several decades. Based on the results of a study of the strength and deformation properties of fine-grained concrete with quartz sand and dispersed reinforcement based on 5% fiber, the following general conclusions were made:

a) Portland cement of the company "Dzhizaktsement" was used as a binder for the preparation of concrete mixtures and concrete samples. The mineralogical and chemical composition of this cement, as well as its main physical and mechanical properties, were determined. Its compressive strength Rv - 39.3 MPa, bending strength Ri = 5.45 MPa, holding time 45 minutes start, end 2 hours, actual density g = 2.95 g / sm^3, pile density rm = 1750 kg / m^3, impact surface, 3200 sm^2/g, softness rate 9.4%, water requirement 27.5%;

b) Quartz sand from the Juma sand quarry in the Samarkand region was used as a fine aggregate. Its main characteristics are given in tables 2.3 and 2.4. The color of the sand is white, yellowish, with a grain size of 0.16 + 2.5 mm, the gravity modulus Mu <2.25 belongs to the category of fine-grained sands. The composition consists mainly of a combination of minerals such as quartz, calcium, feldspar. Its actual density g=2.58g/cm^3, thread density pp=1440kg/m^3, porosity 44%, humidity 4%, water demand 10%, specific surface area 33m^2/kg, average size, hardness 0.30, harmful compounds and components 1%, without organic compounds. The appearance of grains of sand is spherical, angular, flat-angled and x. to;

c) The 5% silica sand used as filler was replaced by the addition of fibres;

d) From the above results, we can conclude that the strength of 28, 60 and 90 days of dispersed reinforced fine-grained concrete based on 5% fiber fiber is up to 20% higher than the strength of the same concrete made of quartz sand. This means that fibrous fibers can be more effective when used as fine aggregates, especially for fine concretes;

e) There is a correct proportional relationship between the cubic and prismatic strength of fine-grained quartz sand, which is determined by the following empirical formula: Rb = (0.77-0.001) • Rb, or Rb = 0.75 R The transition from concrete class to its strength is determined by V = 0.778 Rb or Rb = B / 0.778 with a coefficient of variability Sy = 0.135;

f) The prismatic strength of ordinary heavy concrete after 28, 60 and 90 days is 15.5; 19.3 and 19.7 MPa, respectively. The strength of fine-grained concrete of a similar composition with 3% dispersed reinforcement based on fiber is 23.7; Were 26.1 and 27.7 MPa, respectively. That is, it was noticed that the increase in strength was up to 20%;

g) It can be concluded that when fiber fibers are introduced into fine-grained concrete from quartz sand as a filler, its strength and deformation properties increase significantly. In this case, fibrous fibers, due to their fibrous structure, unite the bond between cement and fillers, forming a mutually strong framework.

Such an effective action of fiberglass plays an important role in the calculation of the strength and deformation of fine-grained concrete with quartz sand. In particular, with the same strength, cement consumption can be saved or efficient structures can be created.

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