KHABIDOLDA OMIRKHAN

STUDYING STRESS-STRAIN STATE AND ASSESSING BUILDING STRUCTURE ELEMENTS STRENGTH TAKING INTO ACCOUNT CRACK-LIKE DEFECTS

ABSTRACT

of the dissertation for the degree
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Relevance of the research topic. The entry of Kazakhstan into the list of competitive and dynamically developing countries of the world requires intense development of the construction industry. This task has acquired the status of a nationwide program. The geographic conditions of Kazakhstan location contribute to the achievement of this goal through the intense construction of multifunctional, unique facilities, transport communications, new industrial enterprises operating on the basis of innovative technologies, industrialization of the country and liberation of the economy from dependence on raw materials. Solving the set tasks will also require accelerated modernization and reconstruction of the majority of the existing enterprises, housing stock, public buildings and engineering structures. Thus, a large amount of construction work is to be performed, implementation of which implies increasing the use of metal, concrete and reinforced concrete structures. Optimal design, efficient operation, real assessment of the technical condition and residual life of construction facilities are closely related to improving the methods of designing building structures.

With developing flaw detection methods, it has been established that building structures contain a lot of microscopic defects that can develop into cracks during operation. These defects can be of natural origin or appear during manufacturing and operation: for example, due to shrinkage of concrete, due to pre-stressing reinforcement, due to shallow welds, as well as due to the force action. When cracks appear, stress redistribution occurs in the cross section, which significantly affects assessing structures strength. In addition, the opening of the crack edges leads to corrosion of reinforcement and reduces its durability.

The occurrence of cracks in structural elements does not mean exhaustion of its bearing capacity. Depending on the modes and operating conditions, the size and nature of cracks, they acquire stable or unstable development, or cannot develop at all. With unstable development of cracks, the destruction of structures can occur, and with stable development of cracks, they can function reliably for a long time. Since there are no defect-free materials, and there is also no way to avoid the occurrence of new defects in the production process, developing the methods of designing elements of building structures with crack-like defects, including those with the presence of cracks, is an urgent scientific problem that has important practical application.

Thus, **the relevance of the research topic** is beyond doubt, it is of scientific and practical interest.

The purpose of the work is to study the stress-strain state of structural elements with crack-like defects and on this basis to improve the methodology of assessing their performance (strength, crack resistance and serviceability).

In accordance with this purpose, the following **research tasks** were formulated.

1. To develop a method of nonlinear analytical design of the stress state of reinforced concrete elements with pre-stressing of reinforcement.

2. On the basis of the planned multifactorial computer experiments and regression analysis, to develop a mathematical model to determine the parameters of the stress state of pre-stressed reinforced concrete elements of rectangular section.

3. To develop an analytical method of calculating the stress state of bent reinforced concrete beams, which makes it possible to determine the crack length and, on this basis, to improve the method of determining the moment by the crack formation.

4. On the basis of the planned experiments and regression analysis, to develop a mathematical model for determining the parameters of the stress state of bent reinforced concrete beams of rectangular section with cracks.

5. To determine the parameters of fracture mechanics in metal structural members with cracks, providing the results in the form of a regression dependence.

6. To determine the stress intensity factor in bent reinforced concrete elements with cracks.

7. To develop a methodology for assessing strength and serviceability of building structural elements with crack-like defects.

Object of study. Elements of building structures with crack-like defects.

Subject of study. The subject of the research is the stress-strain state and assessment of elements of building structures with crack-like defects strength.

Research methods. To determine the preliminary and operational stresses in a reinforced concrete beam, the section method is used. The beam is cut along the section under consideration and the equilibrium conditions for the cut-off part of the beam are compiled. For bent beams, these conditions are reduced to the equality to zero of the sum of projection of all forces on the beam axis and to the equality to zero of the sum of moments of all the forces relative to the transverse axis of the section.

In this case, the hypothesis of flat sections is accepted. In a section with a crack, the linear deformation diagram is transformed taking into account the non-uniformity of deformation along the length of the beam. An exponential law is used to describe the nonlinear relationship between stress and strain in concrete. The main unknown problems are the height of the compression concrete zone and the length of the tension zone above the crack. In the absence of a crack, the maximum (edge) tensile stress in concrete is taken as the second unknown. These unknown values are found from two equilibrium equations. Through these parameters, using the hypothesis of flat sections and the law of deformation, all

parameters of the stress state are determined: maximum compression stress in concrete, stress in reinforcement, crack length or maximum tension stress in concrete, crack opening width.

For the numerical solution of the problem of the stress-strain state of reinforced concrete beams, the FEM is used with the specialized LIRA software package. The beam finite elements are used, taking into account the nonlinear relationship between strain and stress in concrete. In the course of solution, a step-by-step loading method is used with an iterative process at each step. In this case, the sequential exclusion of zones with stresses exceeding the ultimate tension strength of concrete makes it possible to determine the length of the crack in the cross section.

To obtain the dependence of the parameters of the stress state on the parameters of the elastic system, a matrix of rational planning of a multifactorial computer experiment has been compiled. According to this plan, computer experiments have been carried out for bent rectangular beams. Analytical dependences of the stress state parameters, as well as the length and width of the crack opening on the varied parameters, have been obtained by processing the experimental results using the ANETR unconventional regression analysis program.

The scientific novelty of the thesis consists in the following:

- developing a methodology of analytical calculation of the reinforced concrete elements stress state with pre-tensioning of reinforcement in a physically nonlinear setting;
- developing an analytical method of calculating the stress state of bent reinforced concrete beams with cracks and in improving the method of determining the moment by the formation of a crack;
- developing an adequate mathematical model for determining preliminary stresses, parameters of the stress state of bent reinforced concrete elements of rectangular cross-section, including the length and width of the crack opening;
- developing a design model and determining the stress intensity factor (SIF) in bent reinforced concrete elements;
- defining regression dependences for the SIF in the elements of metal structures;
- improving the methodology of assessing the building structures with cracks strength and serviceability.

Scientific propositions and results presented for defense are as follows:

- methods of analytical calculation and regression dependences for determining stresses in reinforced concrete elements on reinforcement pre-stressing;
- an analytical method of determining the parameters of the stress state of bent reinforced concrete beams with cracks and a method of determining the moment by crack formation;
- regression dependences for the parameters of the stress state and cracking of rectangular reinforced concrete beams during bending;

- analytical expressions for determining the SIF in the elements of building structures;

- methods of assessing strength of bodies with crack-like defects taking into account the criteria of fracture mechanics.

Validity and reliability of scientific propositions and conclusions is confirmed by the correct formulation of all the problems to be solved, the use of modern methods of mechanics of a deformable solid, applied mathematical analysis, displaying the results using rigorous logical mathematical calculations, computer modeling, consistency and plausibility of the results obtained and comparing them for special cases with the results of other authors with solutions to test problems.

Theoretical and practical value of the results

1. The developed methods of analytical calculation and the obtained regression dependences for determining stresses on the pre-tensioning the reinforcement make it possible to assess the real technical state of reinforced concrete structural members. These results also make it possible to reasonably select the ultimate tension of reinforcement in manufacturing pre-stressed elements.

2. The developed analytical method and the obtained regression dependences for determining the parameters of the stress state of bent reinforced concrete beams with cracks make it possible to assess the these structural elements strength and serviceability.

3. The developed computational model makes it possible to determine analytically the parameters of fracture mechanics in bent reinforced concrete beams with cracks.

4. The obtained in the work regression dependences for the SIF make it possible to assess the fracture toughness of structures without using software systems.

5. An engineering method of assessing the building structures with crack-like defects strength and serviceability has been developed.

Relationship of this work with other research projects. The work has been performed in accordance with the R&D plans of the KazMIRR Institute under the KTU NJSC (Karaganda), based on scientific and technical comprehensive studies of reliability, durability and assessment of the technical condition of building structures based on contractual research work, in accordance with national programs of improving and developing the construction industry in Kazakhstan.

Approbation of work. The main results of the work were reported and discussed at the following events:

- VII International Symposium "Actual problems of computer modeling of buildings and structures (APCSCE 2018)": (Novosibirsk, Russia, July 1-8, 2018);

- IX International Scientific and Practical Conference "Inspection of buildings and structures: problems and solutions" (Peter the Great St. Petersburg Polytechnic University, Russia, October 11-12, 2018);

- International conference "Integration of science, education and production as the basis of implementing the Plan of the Nation", (Saginov's readings, KSTU, Karaganda, June 14-15, 2019);

- International Scientific Conference "Theoretical and Applied Questions of Mathematics, Mechanics and Informatics" (KSU, Karaganda, June 12-13, 2019);

- 2nd International Conference on Civil Engineering and Architecture, ICCEA 2019 (Seoul, South Korea, September 21-23, 2019).

- scientific seminars of the Mechanics and Mathematics Faculty of KazNU named after al-Farabi (2016-2019, Almaty);

- scientific seminars of the Mechanics Department of Kazakh National University n.a. al-Farabi (2016-2019, Almaty).

Publications

On the topic of the dissertation, the author published 10 works including 3 publications in scientific editions included in the list recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for publication of the main results of scientific activity; 5 publications in scientific journals and proceedings of international conferences indexed by the Scopus database including 1 publication with a non-zero impact factor (CiteScore - 79 percentile, Q2); 2 publications in the proceedings of domestic international scientific conferences.

Personal contribution of the author

The main research results set out in the dissertation work were obtained by the author independently, taking into account the analysis of the currently available scientific works in the investigated field of solid mechanics.

The structure and scope of the dissertation. The dissertation work consists of a title page, a content, designations and abbreviations, an introduction, four sections and recommendations for the use of the results, a conclusion, a list of used sources that includes 214 items. The total volume of the dissertation is 190 pages, including 38 illustrations and 25 tables.

The main content of the dissertation

The Introduction reflects the following points: the relevance of the topic of the dissertation research, the main purpose of the work, the object, the subject and methods of research, scientific novelty, scientific and practical value of the dissertation work, the degree of its elaboration.

The First chapter provides an overview of works on the calculation of bodies with crack-like defects. The emphasis is on steel structures and reinforced concrete structures. The analysis of existing methods for calculating reinforced concrete structures is carried out. There are analyzed the calculation methods of determining the performance criteria.

The existing instrumental methods of detecting and measuring cracks are also outlined.

Alongside with the analytical calculation methods, the necessity of using the finite element method of determining the stress-strain state of a building structure with cracks and calculating the parameters of fracture mechanics is substantiated. The LIRA software package is used to study the stress state of bent reinforced

concrete structures with cracks, and the ANSYS software package is used to determine the parameters of fracture mechanics.

The Second chapter is dealing with studying the stress-strain state of bent reinforced concrete structures with cracks. At the beginning, the stress state of the reinforced concrete element dependence on the pre-tensioning of the reinforcement has been studied; the limiting value of the pre-tensioning of the reinforcement at which a crack appears at the manufacturing stage has also been determined.

With the use of the LIRA software package, multifactorial computer experiments were rationally planned and carried out to determine preliminary stresses in reinforced concrete elements of the rectangular cross-section. By processing the results of the experiments using the program of unconventional regression analysis ANETR, analytical expressions were obtained to determine pre-stresses in reinforced concrete elements made of classes B25 and B40 concrete.

There has been proposed a new method of determining the moment by the formation of a crack with developing an original analytical method of designing bent reinforced concrete beams with a crack, which makes it possible to determine all parameters of the stress state including the crack length.

Based on the FEM and using the LIRA software package, a method has been proposed of numerical solving the problem of the stress-strain state of bent reinforced concrete beams. The matrices of rational planning have been compiled and computer experiments have been carried out to determine the stress state in rectangular beams made of concrete B25 and B40. By processing the experimental results using the ANETR program, regression dependences of the stress state parameters on the variable factors of the elastic system have been obtained.

The Third chapter describes the methodology of the automated calculation of fracture mechanics parameters using the results of finite element modeling; at this, using the ANSYS PC, there have been solved the plane problems of fracture mechanics for rectangular plates of finite dimensions with different locations of cracks. Regression dependences of the SIF on the geometric parameters of the crack and the object have been obtained for rectangular plates of finite dimensions with different locations of cracks. An approximate analytical solution to the problem of determining the SIF in bent rectangular reinforced concrete beams in a linear and non-linear formulation has been developed.

In the Fourth chapter, one- and two-parameter fracture criteria for metal structures have been obtained, which allow determining the breaking load for an existing crack or determining the critical crack length for a given load.

The deformation criterion of fracture has been developed and new one- and two-parameter criterion relations have been obtained, which make it possible to evaluate strength at large local elastoplastic strains through the criteria of linear fracture mechanics, the SIF.

Analytical expressions have been obtained to determine the safety factor for the crack length for all considered criteria of fracture mechanics.

Based on generalization of various approaches to fracture toughness calculations, the method of strength calculation of metal structures with crack-like

defects has been improved and recommendations have been developed for designing reinforced concrete structures with cracks reflecting the main research and applied results of this dissertation work.