ANNOTATION

Ph.D. thesis on the specialty 6D072900 - " Civil engineering "

Duissenbekov Bolat Kambarovich

Investigation of the strain – stress state of shallow shell coatings on the basis of nonlinear equations of creeping

Relevance of the research topic. At the present stage of development of the construction industry in the Republic of Kazakhstan, considerable attention is paid to advanced volume-spatial solutions of modern buildings and structures, the reliability of their design solutions and architectural expressiveness. Currently, both in Kazakhstan and in developed countries around the world, there has been widespread construction of large-span facilities (such as airports, train stations, concert halls, exhibition pavilions, stadiums, entertainment complexes, industrial structures for various purposes and etc.), which are the embodiment of technological progress. During the construction of such facilities, the roof structure and its connection with the bearing elements are the most critical element.

Recent research findings seemed to indicate that the problem is being successfully resolved by using thin-walled spatial shells of various structural forms and materials. Efficient shallow shell structures such as long cylindrical shells, shell panels, shells of positive Gaussian curvature, etc. have exceptionally ample opportunities, both in terms of the reliability of their long-term operation, and in the creation of new expressive architectural forms. Among the listed roof structures, the most functional and advanced, in our opinion, are shells of positive Gaussian curvature, through the use of which 1.5 million m^2 of usable area was built in Europe, and 1.0 million m^2 was built in Russia.

The most commonly used materials for their construction are: reinforced concrete, sheet and rolled steel, plastic, wood, polymer and composite materials. But the dominant value in the manufacture of flat shells is reinforced concrete. This composite heterogeneous material is relatively cheap, flame-resistant, and well resists external influences (precipitation, aggressive chemical elements, temperature changes, etc.). Thanks to the possibility of a wide variation in the class and composition of cement, the addition of plasticizers, the use of different reinforcement and the construction of the reinforcement frame, it is possible to achieve the required design qualities of the manufactured thin-walled spatial shells. This material has a number of specific features, which include linearity and non-linearity of deformation depending on the loading stage, creep, crack opening, without complete loss of load-bearing capacity, etc. If these properties studied enough with the calculation and design of common reinforced concrete elements (columns, beams, slabs, beams, etc.), do not use when introducing spatial thin-walled shells, then there will be excess inventory, reduce economic efficiency and financial attractiveness of the fabric coating systems. As far as is known, an improvement of effectiveness of capital investments, achieved mainly due to a decrease in the material consumption of structures, a decrease in labor costs and a reduction in construction term play a large role in the development of the economy. According to foreign studies, the use of complex large-span spatial roof systems, taking into account the real conditions of their operation and the properties of materials, makes it possible to reduce the cost of bearing structures to 7% and structures in general to 4%.

Despite the obvious advantages of large-span thin-walled roof structures and their continuous improvement, they are rarely implemented in construction practice. According to experts' opinion engaged in scientific research in this area, the limiting factors are the lack of reliable calculation systems due to the complexity and multifactorial nature of the physical processes occurring during the operation of thin-walled spatial structures, in particular shells of positive Gaussian curvature; insufficient number of field experimental studies. There are no consensus on the results of numerical modeling of studies with different approaches to solving this problem, no complete verification of computational software systems, no possibility of carrying out a complete analytical comparison of the calculated and experimental data obtained on the stress-strain state (SSS), etc.

With prolonged exposure to the load, they can manifest the creep property of the material, i.e., the change in time of deformations and stresses under constant load, which can lead to a loss of strength or even to a loss of stability. Since the theory of creep is a relatively young science, solving problems of stability and determining the stress-strain state for flat shells, taking into account the creep of the material, is relevant.

This paper presents an extensive material on the experimental study of flat shells and an overview of the work in the study of structures taking into account the creep of the material. But the author is based only on the experimental results of other authors, and he develops the numerical-experimental part. As a result, it compares its data with the results of other full-scale experimental solutions.

Insufficient knowledge and imperfect design base are the cause of deformations and accidents of the considered coating structures. The most famous is the accident of the entertainment complex "Transvaal Park" (Russian Federation, Yasenev, 2004), according to the results of the study of which the expert commission concluded: "It is necessary to continue work on the development of a calculation device and programs for the analysis of nonlinear creep deformation, cracking and destruction, reinforced concrete statically indeterminate structural systems".

Currently used in the Republic of Kazakhstan software systems LiraSAPR-2015, ROBOT, SCAD, ANSYS, COSMOS-M are updated and are in good agreement with the requirements of Eurocodes. They take into account international requirements, which contributes to the study of monolithic not only complex structures, but also prefabricated elements and even entire construction projects. All the most well-known computational complexes are based on the finite element method (FEM), which allows them to be used, taking into account the physical and geometric nonlinearity, the creep of the material and a number of other very important factors.

But, despite the advantages of the above-mentioned computer programs, they do not cover all the specific features of the calculation of spatial long-span covering systems and, in particular, shells of positive Gaussian curvature.

That is why the research focuses on developing a new computer program that allows more precisely to define the stress-strain state, deformations of thin shallow shells on the basis of nonlinear creep equations, as well as their verification and proof of the reliability of the results obtained by comparing with real field datathan existing programs. So that it is relevant and in demand at the present stage of development of construction.

Purpose of the dissertation research. The purpose of this work is to develop a new method for calculating flat reinforced concrete shells of positive Gaussian curvature based on VAT refinement by taking into account the physical, geometric nonlinearity and creep deformations of the material and using numerical calculation methods.

The following tasks were solved to achieve this goal:

- an algorithm for calculating flat reinforced concrete shells has been developed, which makes it possible to solve the problem of determining the VAT parameters taking into account the physical, geometric nonlinearity and creep deformations of the material;

-finite-difference equations of flat shells are derived taking into account creep deformations, geometric and physical nonlinearity;

- the VAT of flat shells is investigated on the basis of nonlinear equations of material creep under long-term loads;

- the analysis of the VAT of flat shells and the influence of physical and geometric nonlinearity is carried out.

Object and subject of the research. The object of research is shallow shells of positive Gaussian curvature. The subject of research is SSS, the stability of shallow shells, taking into account the physical, geometric nonlinearity and the process of changing the creep deformation.

Scientific novelty of the research:

- developed an algorithm for solving geometrically and physically nonlinear problems and problems of material creep deformation based on the finite difference method (net method);

- developed a mathematical model of deformation of shallow shells, taking into account the physical, geometric nonlinearity and the material creep;

- developed a program based on “DELPHI-7”, which in time calculates the parameters of the stress-strain state of a shallow shell taking into account the nonlinear creep equations;

- shown that the process of deflection growth increases under long-term loading and it can lead to a loss of stability of a shallow shell;

- found that verification of the geometric and physical nonlinearity allows to calculateprecisely the parameters of the stress-strain state of the shell, leading to a loss of stability under long-term loads;

- revealed that the developed program, when calculating shallow shells, takes into account the real properties of the material, which is 6 ÷ 8% more economically efficient than the modern LIRA-SAPR 2015 program. This is due to the derived finite difference equations of shallow shells taking into account creep deformations, geometric and physical nonlinearity of the material.

Practical relevance:

- program and methodology for the study of shallow shells developed on the basis of “DELPHI-7” can be applied in research and design organizations, in the educational process, in scientific research institutes and government expert reviews;
- calculation of shallow shells, taking into account the real properties of materials, will provide an economy of load-bearing structures up to 7% and reduce the cost of structures by 4-6%, by taking into account physical and geometric nonlinearity and creep of the material;
- developed methodology and the program based on it allow for rapid performance of estimation taking into account nonlinear creep.

Research methods. Theoretical and numerical-analytical studies using associated methods of modern computers to determine the stability of flat shells.

The stress-strain state was calculated using the grid method based on finite difference equations, using a software package based on "DELPHI-7", taking into account the regulatory and technical documentation due to the transition to Eurocodes.

An algorithm for calculating flat shells taking into account the nonlinear creep of the material and comparing the results with experimental data.

Implementation of work. The scientific results have been introduced into the educational process of the M.Auezov SKU (in the lecture complex on the discipline “Special course on building structures”).

The program for the calculation of shallow shells, taking into account the nonlinear creep of the material, has been implemented in JSC "Kazakh Research and Design Institute of Construction and Architecture", in the design organization "Otau Stroy" LLP and in the Construction Department of the Turkestan region. The author also received a positive opinion on the grant of a patent for a utility model (registration number 2020/0983. 2 dated 04.11.2020).

The reliability of the research results is confirmed by the numerically tested method for studying the stress-strain state, comparisons of the obtained data with theoretical and experimental data of other scientific researchers, as well as the use of reliable relations between the theory of creep and plasticity during deformation of a shallow shell.

The fundamental principles for the defense:

- program developed on the basis of “DELPHI-7” for calculating shallow shells taking into accountcreep of material;
- methodologyfor studying the creep of a material based on the finite difference method and a computational program on a PC for the stress-strain state of shallow shells;
- identification of the accepted load on shallow shells from the terms of stability;
- investigation of stability loss of shallow shells taking into account the material creep and the stress-strain state of the shell under long-term loading;

- analysis of physical and geometrical parameters of stress-strain state of shallow shells, leading to the loss of stability of shallow shells.

Link with research plan and national programs. The work was carried out in accordance with the research plan of the M. Auezov South Kazakhstan State University B-16-04-13 “Study of the operation of civil buildings of various structural schemes under various loads and influences”.

The work was carried out in accordance with the State Program of infrastructure Development "Nurly Zhol" for 2015-2019 "Task 2. Development of industrial infrastructure and tourist infrastructure. Improvement of architectural, urban planning and construction activities" (Resolution of the Government of the Republic of Kazakhstan No. 1030 of April 6, 2015).

Evaluation of work. The research results were reported and discussed at the International scientific conferences “V International Scientific Practical Conference“Industrial technologies and engineering” (Shymkent, Republic of Kazakhstan),“XIV International scientific and practical conference “Questions of the future from the world of science-2018” (Sofia, Bulgaria), International Scientific and Practical Conference “Auezov Readings - 16: The Fourth Industrial Revolution” (Shymkent, Republic of Kazakhstan), International Scientific and Practical Conference “Improving the Quality of Education, Modern Innovations in Science and Production-2018” (Ekibastuz, Republic of Kazakhstan).

Personal contribution of the author involves:

- development of a finite difference system of equations in *mixed form* for calculating hinged-based shallow reinforced concrete shells for a short-term load action, taking into account physical and geometric nonlinearity, as well as cracking, which allows taking into account the change in stiffness parameters depending on the level of loading.

- development of a finite-difference system of equations in *displacements* for calculating shallow reinforced concrete shells with rigid edges for a short-term load action, taking into account physical and geometric nonlinearity, as well as cracking, which allows taking into account the change in stiffness parameters depending on the level of loading.

- development of a program for the numerical implementation of the developed equations on computers.

- construction of an algorithm and development of a program for calculating stresses, deformations, displacements, crack distribution schemes, as well as for determining a long-term critical load or critical time of reinforced concrete shells.

Publications. The main results of the thesis were published in 9 scientific papers, including 1 article in a journal included in the Scopus / Web of Science database (Thomson Reuters), 4 articles in journals recommended by the Committee for the Control of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, 4 theses in the materials of International Conferences, including 1 article in the materials of a Foreign Conference.

The structure and scope of the thesis. The thesis consists of five main parts, conclusions and recommendations, a list of references and appendices. The main content of this work is presented on 177 pages and includes 33 figures and 7 tables.