The State and Prospects of the Issue of Assessing the Fire Resistance of Reinforced Concrete Structures

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Abstract. The paper considers the main approaches to assessing the limits of fire resistance of reinforced concrete structures. It shows what regulations are guided by the use of certain methods. The key elements of the evaluation processes were described. Practical examples show the advantages and disadvantages, in particular the impossibility of using calculated methods to evaluate new building materials and structures, the characteristics of which are significantly deviated from the available in the calculation manuals. The convergence of the results of the experimental method of assessment and computer modeling has been shown. Conclusions have been drawn on the need to optimize the calculated methods and the possibility of using modeling methods to pre-assess fire resistance limits to optimize performance, followed by experimental confirmation.

1. Foreword
At present, the development of the construction complex has led to the emergence of a large range of construction structures, in particular, the range of reinforced concrete structures has a huge number of names. In addition to the fact that such structures differ in spatial location (horizontal and vertical), by the nature of the work (bending and compressed), a strong difference is observed in the analysis of similar structures applied in different conditions, which affects their geometric and mechanical characteristics and establishes different requirements for performance.

The development of new types of reinforced concrete structures requires a comprehensive approach in optimizing performance, as well as a comprehensive analysis of the facility being developed using calculated as well as experimental assessment methods. As you know, the onset of the extreme states of such structures, during the operation, including in the event of various negative impacts, leads to significant consequences. Negative impacts on structures are associated with emergencies such as fire or explosion of household gas, and the deterioration of performance leading to lower structural limits may be caused by improper operation of structures and the impact of adverse environmental conditions on them.[1-3]

2. Regulatory requirements
The main regulatory document establishing the requirements for reinforced concrete products is GOST 13015-2012 "Concrete and reinforced concrete products for construction. General technical requirements. Rules for acceptance, marking, transportation and storage". This document reflects the
The basic requirements for the concrete and fittings used in reinforced concrete products, geometric parameters of products, including the thickness of the protective layer of concrete.

The design requirements for reinforced concrete structures are set by SP 63.13330.2018 "Concrete and reinforced concrete structures. General provisions". The document presents the basic requirements and procedures for calculating the structures depending on the load to ensure their strength.

A key characteristic of the safety of concrete and reinforced concrete products is a condition in which the effort from external loads \( F \) and impacts should not exceed the limit effort \( F_{\text{ult}} \) that can be perceived by the element.

\[
F \leq F_{\text{ult}}
\]  

(1)

Fire safety requirements are determined by the Federal Law №123 «Technical regulations for fire safety requirements». Fire resistance and fire hazard class of construction structures should be provided through their design decisions, the use of appropriate building materials, as well as the use of fire protection. The document outlines the main limits of fire resistance. The document provides a classification of construction structures by fire resistance and information about the limits of fire resistance, as well as the importance of fire resistance limits depending on the type of construction and the degree of fire resistance of the object.  

The main limits of the design include loss of carrying capacity, loss of integrity and loss of insulation ability. For construction structures it is necessary to confirm the limits of fire resistance, which are determined by calculated and experimental methods.

3. Methods for assessing fire resistance limits

Due to the specifics of different materials and structures, there are several approaches to determining the limits of fire resistance. The most obvious method is to conduct natural tests to ensure conditions similar to the development of fire in real conditions.

To conduct an experimental definition of fire resistance limits, the methods of GOST 30247.0-94 "Elements of building constructions. Fire-resistance test methods. General requirements" are used. This standard includes a description of stand equipment, which includes test furnaces with a fuel supply system, device for installing samples and registration devices. In this case, test furnaces should allow the design elements to be tested in an upright or upright position, depending on their operating conditions. In addition, there is an dependence that provides temperature in tests:

\[
T - T_0 = 345 \log_8 (8t + 1)
\]  

(2)

where the temperature in the furnace \( T, ^\circ C \) depends on the initial temperature to the heat exposure \( T_0, ^\circ C \), and the time emanating from the beginning of the test \( t, \text{min} \).  

Based on the large volume of test data, a large number of dependencies were compiled to calculate the fire resistance limit for loss of carrying capacity. The calculation methods consist of two tasks: thermal and static. The solution to these tasks is to determine the effect of thermal impact on the mechanical characteristics of the design in accordance with the condition (1). Previously, the calculation of fire resistance limits is carried out in accordance with the Manual for determining the limits of fire resistance of structures. The limits of the distribution of fire by the structures and groups of combustion of materials, but due to its cancellation of the current voluntary application documents are currently the STO 36554501-006-2006 «Fire Resistance and Fire Safety of Reinforced Concrete Structures» and the Manual for calculating fire resistance and fire safety of reinforced concrete structures of heavy concrete to this, developed for this organization standard.  

A significant drawback of the current standard settlement methods is due to the fact that they are based on outdated experimental data and estimated dependencies and standard values for materials used in the constructions not covered by the full range of reinforced concrete structures and materials used in them. In addition, it is not possible to assess the behavior of the structure in fire conditions during the calculation, as the solution to the thermal problem is to assess the heating of the rebar through a layer of concrete. Features of the behavior of materials with different characteristics, as well as elements of prefabricated monolithic reinforced concrete structures is an urgent task in connection with the development of this direction.
4. Materials and methods
In view of the above, choosing a method of pre-estimating the fire resistance limit with the ability to fully evaluate the structure under study is an urgent task.

Ansys software complex was used to solve this issue and compared the data obtained during the calculation and in the course of modeling with experimental data of the assessment of the fire resistance limit of the reinforced concrete slab. An analysis of the effectiveness of the selected assessment methods has been carried out. The object for the study is a slab of ceiling of the B40 class of concrete (6170x2350) mm, 180 mm thick with strained fittings in the form of ropes brand 12K7-1500C in accordance with GOST 13840-68.

The experimental fire resistance assessment obtained data on temperature changes on the unheated side of the structure and on the deflection of the structure. To estimate the temperature change, thermopairs were installed at checkpoints in the center and in the middle of the straights connecting the center and angles of the sample. Additional thermopairs were also installed at a depth of 30 mm and 130 mm from the unheated surface for a more detailed analysis of the warm-up of the structure. To assess the deflection, a sensor was installed in the center of the unheated side of the structure. The test mode corresponds to dependence (2), which is based on the sensor data installed in the fire chamber reflected in Figure 1. During the tests, the slab was exposed to a distributed load of 350 kg/m2 (a total of 5 tons).

Figure 1. The dependence of the average temperature (Real) in the furnace's fire chamber from the time of the thermal impact on the sample (τ) (Standard temperature mode accordance with GOST 30247.0-94).

Figure 2 shows a change in temperature under the standard fire exposure.
Figure 2. Temperature at control points of construction structure.

In accordance with the requirements of GOST 30247.1-94, the maximum value of the deflection is L/20 mm. The limit for loss of insulation capacity (I) is an increase in temperature on the unheated surface of a structure averaging more than 140 °C or anywhere on this surface by more than 180 °C compared to the temperature of the structure prior to the test. In this situation, the critical value is the temperature 201°C. The time to reach the bend limit as a result of the tests is 135 minutes, the time to reach the temperature limit is 120 minutes, respectively, the limit of fire resistance of the structure is 120 minutes.

Calculation on the basis of the fire resistance allowance showed a result of 128 minutes.

The simulations in the software complex reproduced the conditions of natural tests. The design scheme is presented in Figure 3.

Figure 3. Computer model of the subject being studied.
During the analysis, the temperature distribution fields of the object were obtained, as shown in Figure 4.

Figure 4. Distribution of temperature by plate.

The critical warm-up temperature is reached in 120 minutes. Figure 5 shows the bend of the structure when exposed to a given distributed load.

Figure 5. Bending the stove when exposed to heat under the influence of distributed load.

As can be seen from the presented drawings, computer modeling provides an opportunity for a more detailed analysis of the process of fire impact on the structure under the influence of loads.[10,11] As in natural tests, it is possible to assess the temperature impact at different points of the structures. In addition, in-kind tests and computer simulations allow you to deviate from the standard temperature dependence (2) in case the conditions of a fire hazard or features of the study of the behavior of the structure require this.
In practice, there is a need to improve the performance of concrete in order to increase the efficiency of the structures, improve the quality of life and ensure safety. The ability to change the performance of reinforced concrete products is achieved in several ways:

- selection of concrete and rebar in accordance with the required criteria (including the selection of concrete with the introduction of fire-resistant additives)
- Development of prefabricated concrete structures

In all cases, it is possible to conduct in-kind tests to determine the limit of fire resistance and to conduct detailed analysis to assess the behavior of the design during tests. At the same time, computer modeling allows. However, the conduct of mathematical calculations according to the standard method in many cases does not allow to take into account the characteristics of new building materials and the behavior of the construction structure. An example of such structures are the industrial monolithic reinforced concrete structures using concrete blocks.

5. Conclusion
Based on the analysis and study of the results of the assessment of fire resistance limits in various ways, it can be concluded that at present one of the important tasks at present is to optimize the calculation methods taking into account the features of modern building materials and structures. At the moment, one of the most effective ways to assess the limits of fire resistance is the use of computer simulations using specialized software systems. Their use allows to optimize the performance of the structures with further confirmation of experimental methods.

6. References
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Acknowledgments
This work was financially supported by the Ministry of Science and Higher Education of the Russian Federation (Project: Theoretical and experimental design of new composite materials to ensure safety during the operation of buildings and structures under conditions of technogenic and biogenic threats #FSWG-2020-0007).