Features of modelling reinforced concrete structures in order to give fire resistance

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Abstract. The work explores the problem of assessing the limits of fire resistance of modern construction structures. Existing experimental methods are a fairly accurate way of assessing and are used in the certification of construction structures. Nevertheless, a significant problem in the development of new construction structures arises the problem of the need to conduct a large number of complex and expensive tests. Calculated evaluation methods are a reasonable alternative for pre-evaluating the effectiveness of the solutions developed. However, at present such calculations do not take into account the different types of design solutions and properties of new building materials. The work provides the results of experimental and calculated methods of assessing the limits of fire resistance. The analysis of the calculation results showed that when using regulatory documents in calculating the actual limit of fire resistance, the results differ by a maximum of close to 20 minutes. Thus, it can be concluded that the data obtained by the standards may produce inflated results. Currently, there are quite a lot of software products capable of solving such problems at a high level. One of the most powerful software complexes is ANSYS. This product allows you to construct a mathematical model of the object to conduct complex engineering calculations to determine the likely failure scenarios and parameters of control of the tensely deformed state of construction structures Object. A simulation of the behavior of a reinforced concrete slab during a fire, with the help of the ANSYS program, is shown.

1. Foreword
Analysis of fire statistics, especially residential buildings, indicates that the collapse of the building is possible due to insufficient fire resistance of their main supporting structures, as a result of underestimation of their fire resistance limits when changing functional class of danger groups of premises and parts of the building.

Every year in the urban development zone (30% in Russia), in buildings from 6 to 25 floors there are more than 10000 fires that kill about 500 people. Up to 20000 fires for the year occur in buildings of the first and second degree of fire resistance (more than 70% of modern buildings) and the result is the death of more than 1000 people [8]. In buildings more than 25 storeys high, the death rate from fires increases by 3-4 times. The construction of high-rise buildings, large-span structures or unique structures inevitably leads to the development of new technologies and materials, as well as design techniques [14].

The main indicator that determines the level of safety of the object is fire resistance - the ability of the construction structure to maintain the supporting and/or fencing functions of the main supporting...
structures in the conditions of fire. Fire resistance characterized by the limits of fire resistance and the spread of fire. The limits of fire resistance of construction structures are determined by their fire tests according to the standard method and are expressed by the time of impact on the construction structure of a standard fire reaching one of the limit states. The document establishing the general requirements for fire resistance and fire hazard of buildings, structures, buildings and fire compartments is Federal law No. 123 "Technical regulation on fire safety requirements" (Article 35 p.2, 87 p.9-10) [2].

In real conditions of construction, reconstruction in monolithic and panel building there is no system to confirm the compliance of the actual limits of fire resistance (this is especially important for bearing construction structures, especially overlaps buildings, as well as the shells of tunnel structures) required by legislation (Article 87 and Table 21 annexes to Federal law No. 123) [2]. Numerous experimental fire tests of such structures show that the fire resistance limit of the buildings and structures operated may not meet the required design values in 50–60% of cases. An example is the explosion in the operated apartment building, Magnitogorsk, 2018. The explosion led to the progressive collapse of structures from the third to the tenth floors in the section of the building.

2. Materials and methods
The object of the study are ways to assess the limits of fire resistance of structures. The actual limits of fire resistance structures are currently determined by two main ways: experimental and calculated.

The experimental method of determining the limit of fire resistance is the most common and reliable. Fire resistance of construction structures is determined on the basis of the testing of design samples in special fire installations and is characterized for this design by the limit of fire resistance, determined by the time (minutes) from the beginning of the thermal tests until the limit state of construction is reached. Product compliance with the stated fire resistance indicators is certified solely on the basis of experimental methods [1, 3].

Methods for determining the limits of fire resistance of construction structures and signs of limit conditions are set by fire safety regulations: GOST 30247.0-94 "Construction structures. The method of testing for fire resistance. General Requirements" and GOST 30247.1-94 "Construction structures. Fire resistance testing methods. Carriers and fencingstructures." Samples tests were carried out in accordance with the requirements of GOST 30247.1-94. The tests are carried out under the standard fire mode, the temperature regime according to GOST 30247.0-94. The limit states for loss of carrying capacity (R) are the maximum bend value is L/20 mm and maximum rate of build-up of deformations (cm/min) [4].

Numerous tests of building structures on fire resistance have revealed the main causes and nature of the destruction of reinforced concrete, steel, wood and other structures when exposed to fire, as well as the features of their warming in these conditions [10]. The generalization of the results of fire tests made it possible to create a list of reference data, which can determine the values of the actual limits of fire resistance of major construction structures - Benefit for the definition of limits fire resistance of structures, limits of fire spread and groups of combustion of materials [6, 7].

Calculating the fire resistance of construction structures involves solving two tasks:
1) The strength task of fire resistance: determining the normative workload on the construction structures, the value of the ratio of the working conditions of the construction materials in a fire, the value of their critical temperature Heating at this workload level.
2) Heat-physical fire resistance task: determining the time of fire impact on the construction structure, at which key elements of the structure are heated to a critical temperature.

Samples based on which the existing methods of assessing the limits of fire resistance are reinforced concrete slabs of concrete class B40 size (6170x2350) mm, thickness of 180 mm, strained fixture in the form of ropes brand 12K7-1500C GOST 13840-68, with additional reinforcement of fibrofibre fibers.
3. Another section of your paper
As a result of a number of in-kind tests of construction structures, the following data were obtained. The actual fire resistance limit of the construction structure for loss of carrying capacity was 120 minutes (Figures 1-2).

![Deflection of construction structure](image1)

**Figure 1.** Deflection of construction structure

![Temperature at control points of construction structure](image2)

**Figure 2.** Temperature at control points of construction structure

The data obtained using calculated methods based on recommendations for calculating fire resistance gave a fire resistance limit of 137 minutes [6].

The analysis of the calculation also showed that when using regulatory documents in calculating the actual fire resistance limit, the results differ by close to 20 minutes. Thus, it can be concluded that the data obtained by the standards may produce inflated results.

Based on analysis of tests and calculated methods, main problems associated with the fire resistance assessment can be identified as follows:

1. Organizing and conducting an experimental fire resistance assessment of construction structures requires considerable material costs and time. In some cases, it does not allow for rapid enough solutions to assess the fire resistance of structures at the design stage of buildings and structures,
making it difficult to qualitatively assess the impact of various factors on the behaviour of structures in fire conditions.

2. The problem of methods and means of determining changes in the deformat-strength characteristics of building materials in the impact of fire. The urgency of solving this problem is evident in the emergence of new types of building materials with under-studied fire and technical characteristics. It is necessary to analyze the methods of assessing changes in the physical and mechanical characteristics of building materials, including the ratios of their working conditions during exposure to and after the impact of fire.

3. The problem of the need to assess the durability of construction structures, buildings and structures with combined special impacts involving fire. Examples of such impacts are: a gas explosion in a 22-storey large-panel residential building in London in 1968; a series of terrorist bombings that led to the destruction of a 9-story administrative building in Oklahoma City in 1995, an eight-story apartment complex in Saudi Arabia in 1996, high-rise buildings of American embassies in Kenya and Tanzania in 1998 and so on. These events clearly showed that buildings can be destroyed by avalanches. After that, foreign building codes were introduced to protect buildings from progressive collapse. In the development of constructive solutions, emergency situations have been taken into account - man-made impacts, terrorist attacks, the same gas explosions. A striking example of extreme fire impact is the tragedy of September 11, 2001 in New York. After the dynamic impact of the aircraft on the tower and subsequent explosions, the temperature of the fire once took the burning temperature of aviation fuel equal to 1100 °C. While the buildings of skyscrapers have remained stable after dynamic impacts aircraft and subsequent explosions of aviation fuel. The fires that followed caused the fire resistance limit of the Column

4. There is a problem of diversity of fire danger situations (example is also the tragedy of September 11, 2001). Existing methods of experimental research provide for the temperature mode of "standard fire" which is expressed by the logarithmic function of time: t = 345lg (8t_o + 1) (figure 3)

![Figure 3. Temperature mode of "standard fire".](image)

5. Existing fire resistance assessment techniques do not adequately consider the joint work of the various structural elements of the building. In case of fire under the influence of temperature deformations can occur a change in static schemes of structures, the appearance of additional controversial efforts, local collapses of individual parts of the building's carrier system [12]. These factors have a significant impact on the fire resistance of structures and buildings as a whole, which can be both positive and negative [13].

6. There is a significant problem with the database of the actual limits of fire resistance of construction structures as a result of fire tests. Due to the constant emergence of new building materials and technologies, research is constantly carried out on the limits of fire resistance of new
construction structures. However, such information can often be difficult to find. In addition, out-of-date publications (such as the above manual) have data based on outdated methods. The last version of this type of manual was published in 1985 and needs urgent updating, supplementation and re-release [7].

7. Problems related to the assessment of fire resistance of reconstructed and operated buildings. Background data on the range of fire resistance of the most common types of structures are obtained during standard fire tests of structures before their operation, so cannot be used in the assessment of fire resistance of the buildings in operation.

The study established the need to adjust the existing method of calculating fire resistance, based only on taking into account the effect of temperature on the characteristics of concrete and reinforcement in the section of elements. The method currently used leads to an error of calculations. This error is present in the normative materials. To address this shortcoming, proposals should be made to clarify a methodology that includes the use of non-linear methods, in particular a non-linear deformation model, not only when assessing the strength of sections of reinforced concrete elements.

Almost all parameters that determine the transfer of stresses to concrete in the current norms are designed for traditional pre-stretch edited reinforced concrete structures using both classic reinforcement rods and reinforcement steel ropes. At the same time, today there are many new types of high-strength concrete and composite fittings, for which the nature of the transmission of pre-load can be significantly different [9].

Every year, more and more developing direction associated with the use of dispersal reinforcement of reinforced concrete fibrosis, which increases the strength and rigid properties of reinforced concrete structures. Fiber fibers can increase the extreme stretching, crack resistance and impact resistance of concrete. The standards do not contain experimental data to calculate fire resistance [11]. In this regard, a test was carried out to obtain results for further calculations of fire resistance limits. Regulatory documents need to be finalized because they do not take into account

The tasks of improving the methods of determining the fire resistance of reinforced concrete construction structures based on mathematical and computer modeling are relevant. The importance of these tasks is due to the laborious ness and high cost of fire tests of reinforced concrete construction structures.

Currently, there are quite a lot of software products capable of solving such problems at a high level. One of the most powerful software complexes is ANSYS. This product allows you to construct a mathematical model of the object to conduct complex engineering calculations to determine the likely failure scenarios and parameters of control of the tensely deformed state of construction structures Object. Also, the result of the calculation can be predicting the algorithm of destruction (accident scenario), the development of safety measures [15].

A simulation of the behavior of a reinforced concrete slab during a fire, with the help of the ANSYS program complex, is shown (figure 4). Based on the results, it is possible to continue using the ANSYS program in the preliminary assessment of fire resistance, in order to obtain more accurate results in comparison with numerical calculation [16].
Figure 4. Temperature change in construction

4. Conclusions
A comparative analysis of the test results and numerical solution of the problem has been carried out. As well as the simulation of the behavior of the reinforced concrete slab during the fire, while considering the mathematical models given in modern regulatory documents. The studies identified actual fire resistance limits and the most effective mathematical models for calculating the fire resistance of bendable and compressed reinforced concrete elements.

The results of the work allow to formulate requirements for the choice of fire retardant materials for reinforced concrete structures with a rational limit of fire resistance and taking into account the criteria of irreversible deformations, including at the design stage, reduction material and social damage.

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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).