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Evaluation of Fire Resistance of Reinforced Concrete Beams on the Basis of Use of Parametric Temperature Curves of Fire Modes

Serhii Pozdieiev[1, a)], Taras Shnal[2, b)], Petro Kholod[2, c)], Svitlana Fedchenko[1, d)] and Inna Nedilko[1, e)]

[1] *Cherkasy Institute of Fire Safety named after Chornobyl Heroes of the National University of Civil Defence of Ukraine, Onoprienka Str.,8, 18034, Cherkasy, Ukraine*

[2] *Institute of Civil Engineering and Building Systems of Lviv Polytechnic National University, Karpinskoho* Str.*, 6, 79013, Lviv, Ukraine.*

[a)]svp_chipbbk@ukr.net
[b)]taras.shnal@gmail.com
[c)]Petro.F.Kholod@lpnu.ua
[d)]Corresponding author: svitlanafedchenko@ukr.net
[e)]kadr2dprz@ukr.net

Abstract. The article considers the calculation method for assessing the fire resistance of reinforced concrete beams under the condition of parametric temperature regime of the fire. Temperature analysis for both parametric and standard fire exposure was performed and the corresponding plastic moments depending on the duration of the fire were determined. On the basis of the conducted research the diagrams of limiting moments for reinforced concrete beams are constructed. These diagrams allow you to check the strength conditions and assess the affiliation of reinforced concrete beams to the appropriate standard class of fire resistance. Using the constructed graphs of dependences of limiting plastic moments on the value of fire duration corresponding to standard classes of fire resistance for reinforced concrete beam, it is concluded that the standard temperature of fire is the most severe and leads to a constant reduction of limiting moment in contrast to others with horizontal branches, due to the descending branch of the calculated temperature of the fire according to the parameters of the room. On average, when using the temperature regimes of fire, determined by the proposed mathematical models, the limiting plastic moments are three times less than the limiting plastic moments determined under the influence of the standard temperature of the fire.

FORMULATION OF THE PROBLEM

In recent decades, a large number of studies on the development of fires, in rooms on full-scale models [1] and small-scale models, which allowed to develop methods of temperature regimes of fires as close as possible to real. The developed methods are reflected in the regulations on the design of building structures in particular to assess the impact of fire [2]. Accordingly, it makes it possible to assess the fire resistance of building structures by temperature regimes of fires close to real [3,4], which will more accurately assess the level of compliance of structures with fire safety requirements and the validity of the fire protection systems of the structure if necessary.

The purpose of this study is to assess the fire resistance of reinforced concrete beams using calculation methods under the parametric temperature of the fire. The objectives of the study were to determine the temperature distribution in the cross section of reinforced concrete beams, to determine and construct diagrams of limiting plastic moments under parametric fire and the temperature regime corresponding to the standard curve temperature - time.

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ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

In the work [5] the review of influence of high temperatures on reinforced concrete designs is given. The reaction of the whole reinforced concrete structures to realistic fires presents even greater challenges due to the interaction of structural elements, the impact of complex structures in full scale on the spatial and temporal changes of exposure, including the cooling phase of the fire. In addition, there is still a serious lack of data from real structures for verification, although some valuable insights can also be obtained by studying the characteristics of reinforced concrete structures in real fires.

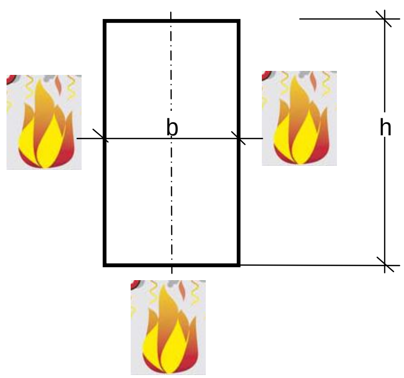
In the work [6,7] it is noted that a reasonable alternative to testing for fire in the near future may be modelling of structures under fire using CAD. The amount of information from the created model far exceeds the results of standard fire tests. The method of modelling of prefabricated reinforced concrete slabs for evaluation of temperature analysis using CAD-system ANSYS is proposed in the work. The adequacy of the simulation environment is confirmed by comparison with experimental data.

In the work [8,9], a method for estimating the fire resistance of steel structures under the influence of temperature conditions close to real ones is presented. The expediency of such an approach to the assessment of fire resistance in comparison with the temperature effect on the standard curve - temperature-time is shown.

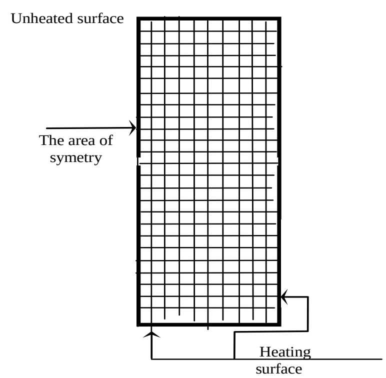
In the work [1] the results of the study of fire development in a three-storey building on the basis of which a parametric model of fire development suitable for assessing the fire resistance of building structures were proposed.

THE MAIN PART OF THE STUDY

To study the temperature distributions along the cross section of reinforced concrete beams under the thermal influence of fire with a mode close to the real one, a calculation technique based on the solution of the nonstationary equation of thermal conductivity was used [2,10]. The section of a reinforced concrete beam with three-sided heating is considered. Schemes of this section are shown in Fig. 1.



a.



b.

FIGURE 1. The scheme of fire impact on the reinforced concrete beam (a) and the corresponding final-difference scheme (*b*).

The Scheme of Reinforcement in the Investigated Beam is Shown in Fig. 2.

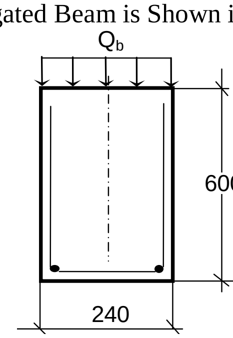


FIGURE 2. Reinforcement scheme in the investigated beam.

Thermophysical properties of the beam are given in table 1, and the boundary conditions for the boundary value problem are given in table 2.

TABLE 1. Thermophysical characteristics of concrete.

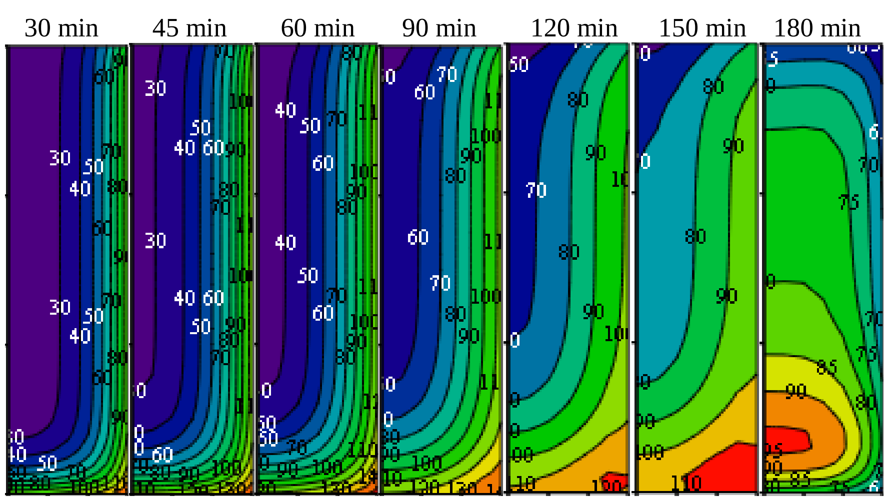
Parameter	Heavy concrete on granite aggregate DSTU-N B EN 1992-1-2: 2012
Thermal conductivity coefficient, $\lambda(\theta)$, W/(m·°C)	$2–0{,}2451\frac{\theta}{100}+0{,}0107\left(\frac{\theta}{100}\right)^2$
Volumetric specific heat, $c_p(\theta)\cdot\rho$, J/(m^3·°C)	900ρ when 20°C≤θ≤100°C, (900+(θ-100))ρ when 100°C<θ≤200°C, (1000+0,5(θ-100))ρ when 200°C<θ≤400°C, 1100ρ when 400°C<θ≤1200°C
Density, kg/m^3	2300

TABLE 2. Parameters of boundary conditions for reinforced concrete beams.

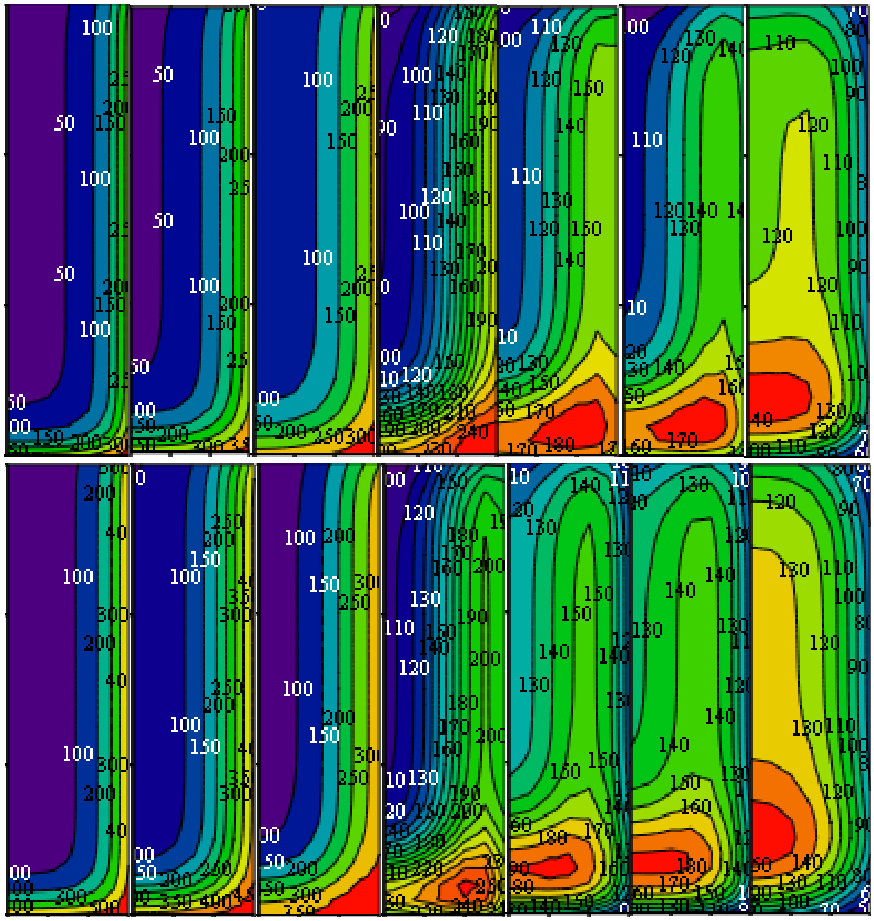
Parameter	Mark	Unit of measurement	Value
		Heating side	
Convective component of the heat transfer coefficient	α_c	W/(m^2·°C)	25
Degree of blackness of concrete			0.7
		Unheated side	
Heat transfer coefficient	α	W/(m^2·°C)	9

After the calculation we obtained the temperature distributions along the cross section of the beam at the control points of time corresponding to the standard series of fire resistance classes R 30 - R 120 for the temperature of the fire, determined by the coefficient of slots O=0.0045 m$^{0.5}$ and three different combinations of fire load density ($q_{t,m}$=500 MJ/m^2, 2–$q_{t,m}$=850 MJ/m^2, $q_{t,m}$=1200 MJ/m^2).

In figure 3 the temperature distributions along the cross section of the reinforced concrete beam during the temperature exposure to fire of the corresponding standard fire resistance class is shown.



a.



b.

c.

FIGURE 3. Temperature distributions in half of the cross section of the reinforced concrete beam 240×600 at different moments of time for the temperature of fire, determined by the coefficient of slots O=0.0045 m$^{0.5}$ and density of fire load (a – $q_{t,m}$=500 mj/м^2, b – $q_{t,m}$=850 mj/m^2, c – $q_{t,m}$=1200 mj/m^2).

For comparison, similar calculations were performed under the standard temperature of the fire. The results of the calculation in the form of temperature distributions along the cross section of the reinforced concrete beam 240×600 are shown in Fig. 4.

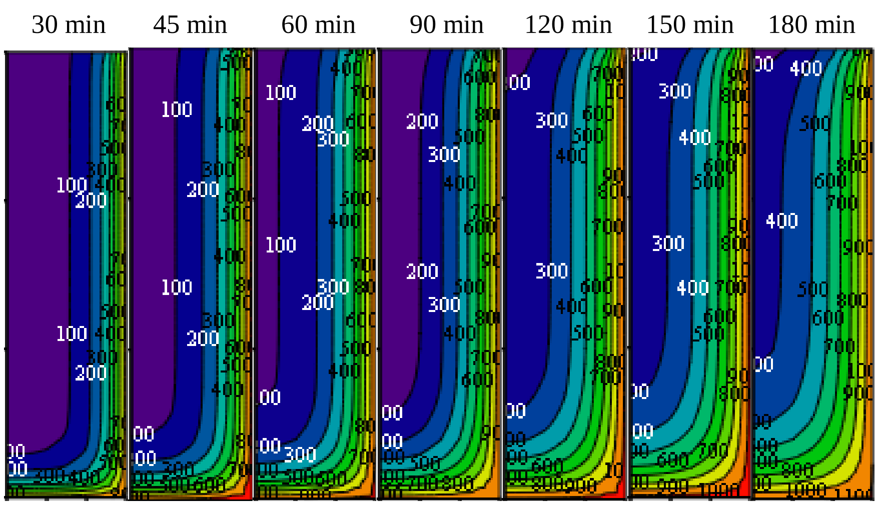


FIGURE 4. Temperature distributions along the symmetrical half of the section of the reinforced concrete beam at different moments of time for the standard temperature of the fire.

The calculation procedures described in the work [2,10] should be used to determine the bearing capacity. Mechanical properties of concrete and reinforcing steel are given in table 3.

TABLE 3. Characteristics of concrete and reinforced concrete beam reinforcement.

Parameter	Reinforced concrete beam
Parameters of reinforcement of edges of a plate of the bottom row	∅25 A500C
Additional	∅8 A500C
Concrete class	C 20/25 (B25)

After performing the calculations [2,11], the limiting plastic moments were determined, which are given in the form of graphs of their dependences on the value of the fire duration time corresponding to the standard fire resistance classes in Fig. 5.

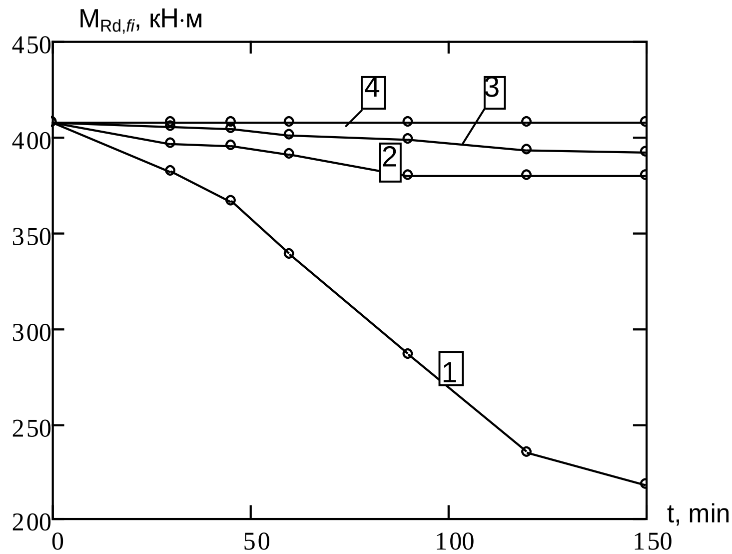


FIGURE 5. Graphs of dependences of limiting plastic moments on value of time of duration of fire corresponding to standard classes of fire resistance for a reinforced concrete beam 240×600 mm at different temperatures of the fire: 1 – standard temperature mode, 2 – temperature mode, calculated at the coefficient of slots O=0.0045 $m^{0.5}$ and density of fire load $q_{t,m}$=1200 mj/m^2; 3 – temperature mode, calculated at the coefficient of slots O=0.0045 $m^{0.5}$ and density of fire load $q_{t,m}$=850 mj/m^2; 4 – temperature mode, calculated at the coefficient of slots O=0.0045 $m^{0.5}$ and density of fire load $q_{t,m}$=500 mj/m^2.

The graphs shown in Fig. 5 show that the standard temperature of the fire is the most severe and leads to a constant decrease in the limit moment.

In order to determine the actual limit of fire resistance for reinforced concrete beams by the developed method, it is possible to use the sequence of procedures presented in the form of a diagram shown in Fig. 6.

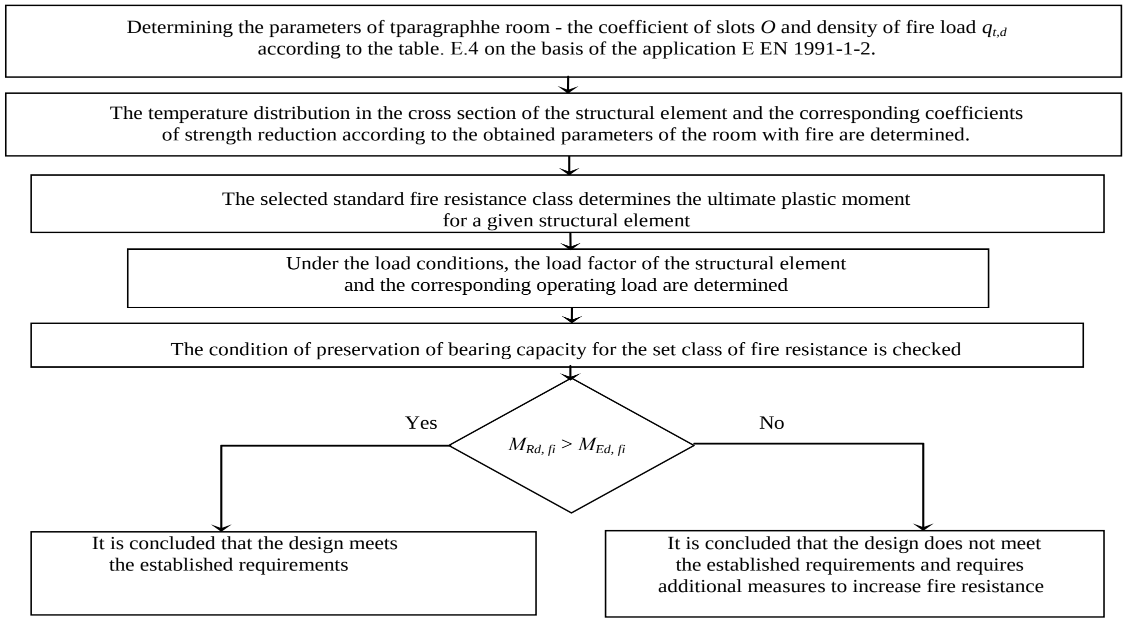


FIGURE 6. The scheme of the calculation method for assessing the fire resistance of reinforced concrete structures by the developed method.

The developed method can be used to determine fire resistance of any elements of reinforced concrete structures of rectangular cross-section in compliance with the basic recommendations of the standards [2, 11].

CONCLUSIONS

Summing up all the above, we can summarize:

- the temperature distributions in the sections of reinforced concrete structures under the conditions of thermal influence of the fire temperature according to the proposed mathematical models, which are used to determine the distribution of reduced mechanical characteristics were studied;
- the regularities of limiting plastic moments for monolithic reinforced concrete beams are revealed;
- diagrams of limit moments for reinforced concrete beams, which allow to check the strength conditions and assess the affiliation of these elements of reinforced concrete structures to the appropriate standard class of fire resistance were constructed;
- it is shown that on average, when using the temperature regimes of fire determined by the proposed mathematical models, the limiting plastic moments are three times less than the limiting plastic moments determined under the influence of the standard temperature regime of fire.

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