Serhii Pozdieiev[1], Yuriy Otrosh[2], Denis Stupak[3], Stanislav Sidnei[4]

Institute of Fire Safety n.a. Heroes of Chernobyl of National University of Civil Protection of Ukraine

Investigation of fire influence on reinforced concrete walls using finite elements method[5]

To reduce the risk of significant social and economic losses during buildings and structures fires it is necessary to ensure concrete walls proper functioning under conditions of thermal fire action, that guarantee their compliance with existing regulatory technical standards that determine their fire resistance limits [1]. Determining the actual limits of fire resistance the method of natural fire tests is the most valid and reliable [1]. The method of fire testing consists in the heating of specimen, which wholly or partly meets the real element of concrete structure in a special fire stove at a temperature range that is defined in the regulations [1 - 3] called standard temperature fire curve, with appropriate application of mechanical stress.

Testing of concrete bearing walls fire resistance is in accordance with the applicable standardsof Ukraine [2, 3]. According to these standards the wall should be subjected to the firing of action in terms of its load and reliance in accordance with the design scheme of the buildingstructure. When implementing such terms there are certain technical difficulties that are innon-compliance of the wall load and fixing in the construction conditions, non-compliance of the sample dimensions for testing and real walls, etc. Besides the method of

An alternative to experimental methods is calculation methods application. At present, the theoretical and methodological framework for such an approach contains a series of regulations [4], valid in Ukraine. These methods are flexible, allowing to take into account all the diversity of limiting conditions, materials, geometric dimensions and others. walls parameters, and they are much less time-consuming and costly.

Many of these methods are based on materials resistance hypotheses and work well when
there is a clear understanding of the construction element conduct under the fire influence. The lack of such information restricts the use of calculation methods, because its obtaining is associated with scale experiments. To solve these problems it is effective to use mathematical modeling involving heavy engineering computer systems based on the finite element method as it provides a large amount of data on the load-bearing walls conduct under the fire influence. In accordance with mentioned above the importance and topicality of bearing concrete walls under the fire influence conduct problems study can be pointed out.

Analysis of recent achievements and publications

In this research [5] the approach of the concrete structures conduct under the fire influence study is provided, which is to conduct mathematical modeling with finite element method (hereinafter - FEM) supplemented with plastic deformation mathematical models, strength theory, model of the material mechanical properties material if there is a crack in integration point, etc. This approach refers to the revised

---

[1] Doctor of Technical Sciences, Sergey Pozdeyev, Professor / Institute of Fire Safety n.a. Heroes of Chernobyl of National University of Civil Protection of Ukraine.

[2] Ph.D.,Yuri Otrosh, associate professor / Institute of Fire Safety n.a. Heroes of Chernobyl of National University of Civil Protection of Ukraine.

[3] Ph.D., Denis Stupak, associate professor / Institute of Fire Safety n.a. Heroes of Chernobyl of National University of Civil Protection of Ukraine.

[4] Stanislav Sidney, adjunct / Institute of Fire Safety n.a. Heroes of Chernobyl of National University of Civil Protection of Ukraine.

[5] Artykuł recenzowany.

calculation methods and enables accurately describe concrete structures elements conduct under the fire influence. In this paper much attention is paid to the behavior of concrete beams and slabs conduct.

As for compressed elements - columns and walls such attention is not paid. Columns work for this approach has been investigated in the article [6]. There are a number of works devoted to the load-bearing walls conduct under the fire influence, detailed analysis are presented in the thesis [7]. But the question of the stress-strain state parameters distribution still remains (hereinafter - SSS) in the section, deformation schemes, defects distribution as well as information on the mechanism and causes of bearing concrete walls destruction under the fire influence.

In this regard, the objective of the study is defined.

The problem statement and its solution

Purpose is to determine the main parameters of the stress-strain state, deformation schemes, distribution of defects, as well as information on the mechanism and causes of bearing concrete walls destruction under the fire influence when using the finite element method.

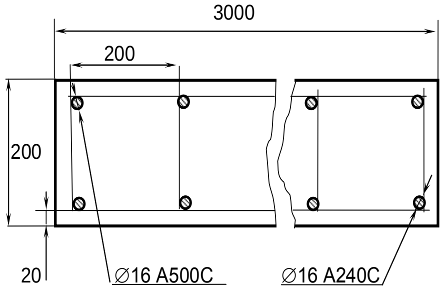


Fig. 1. Scheme of concrete wall reinforcement.

To study the load-bearing concrete walls conduct the concrete wall is considered, the main technical parameters of which are given in the Table. 1.

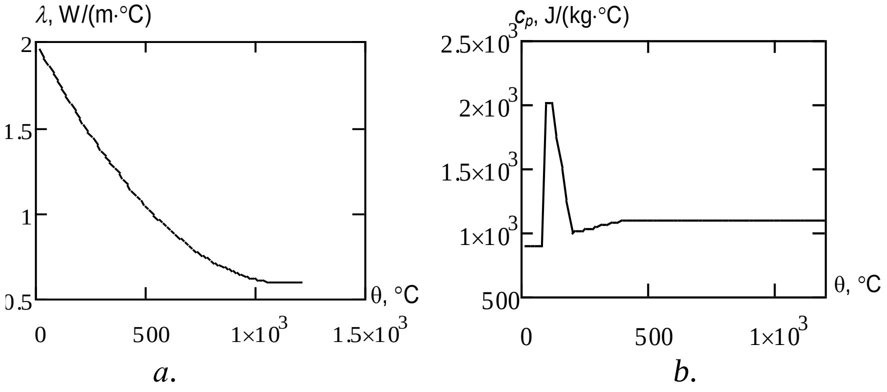
Tab. 1. The main technical parameters of concrete wall.

Parameter	Signs	Value	Unit
Geometric dimensions • width • width of the protective layer • length of the wall • wall height	s w l h	0,2 0,02 3,2 3	m
Concrete type	Heavy with the granite aggregates	Class C 30/35 (B30)	
Concrete density	ρ_B	2300	kg/m^3
Extreme humidity	u	< 3	%
Internal working armature: • diameter	d_1	Class A500C 0,016	m
External working armature: • diameter	d_2	Class A240C 0,016	m
Frame armature: • diameter	d_3	Class A240C 0,008	m

To describe the concrete walls conduct under the fire influence the approaches of such problems solving are analyzed [4, 5]. Approaches analysis in these data sources allows to formulate the basic preconditions and assumptions that can be presented in such general form:

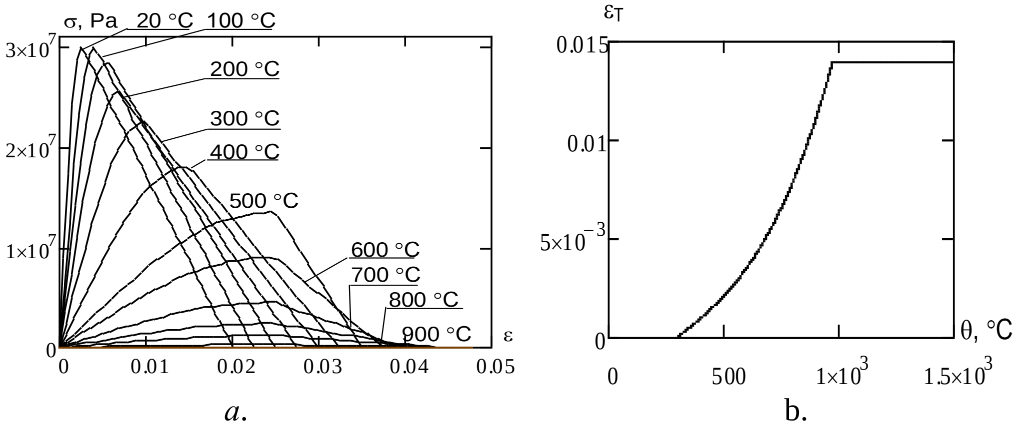
1. Mathematical model of thermal and mechanical reaction to fire thermal influence is described by the heat equation and systems of differential equations of solids SSS in their numerical implementation on the basis of FEM.
2. For the solution of heat engineering problems two-dimensional non-stationary quasilinear heat equation is used with effective thermophysical characteristics (TFH) of concrete according to regulatory documents [4] based on the assumption that the SSS does not affect on them..
3. The possibility of the wall material cracking during its stretching is taken into account, and during its compression the stonework conduct is nonlinear considering descending branch deformation diagrams, the parameters depending on temperature.
4. Concrete cracking is determined by the relevant concrete strength theory.
5. Plastic deformation of the material is determined associative plasticity theory.
6. The wall total destruction condition is defined with extreme deformations associated with the formation of a local plastic deformation zone.

To solve the problem the complex source data usage is required, which include the material properties of the wall, extreme conditions and parameters, taking into account the load application, and thermal effect. Fig. 2 shows the thermal properties of concrete, the wall described in the current standard of Ukraine is made of [4] for calculating the fire resistance of concrete structures. These characteristics are the temperature dependence of effective characteristics that describe the material as homogeneous and isotropic, which is valid for these calculations [4, 5]. Figure 3 presents thermomechanical properties of concrete used for calculation.



a. *b.*

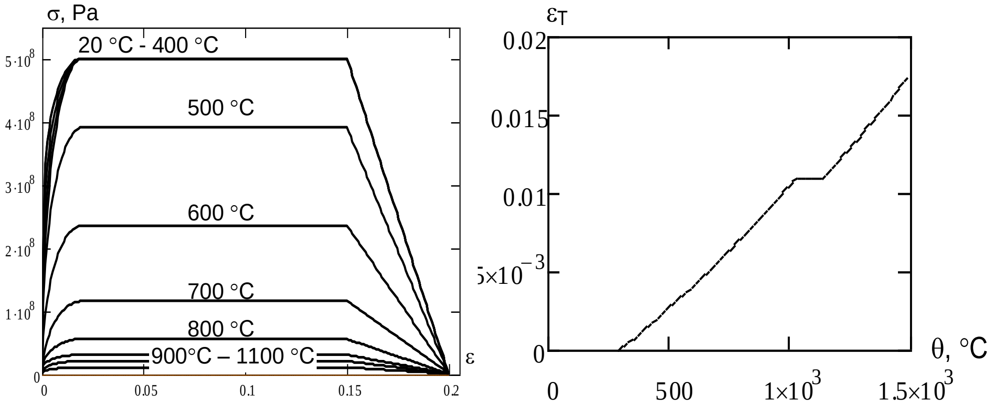
Fig. 2. Blocks masonry of lightweight concrete thermal characteristics, heat conductivity coefficient (a) specific heat (b).



a. b.

Fig. 3. Thermomechanical properties of concrete: deformation diagram (a) thermal deformation (b).

Figure 4 presents thermomechanical properties of reinforced steel



a. *б.*

Fig.4. Thermomechanical properties of reinforced steel: deformation diagram (a) thermal deformation (b).

For the calculation mathematical models parameters of which are given in Table 2 are used.

Tab. 2. Basic mathematical model for the wall fire resistance calculation.

Wall material conduct features	Mathematical model (method) used	Source
Thermotechnical task		
Heat conductivity	Nonstationary heat conductivity equation with FEM	[5]
Extreme conditions	III kind	
Physical nonlinearity	Iterative method of Newton-Raphson	[5]
Static task		
SSS	FEM	[5]
Plastic deformation	Associative Theory of plastic deformation by Besselig	[5]
Cracking	Composite criterion of concrete strength by Willem and Warnke	[5]
Nonlinearity	Iterative method of Newton-Raphson	[5]

For the calculations calculation scheme of heat engineering and static tasks shown in Fig. 5 were accepted.

Used characteristics meet standard specifications of Ukraine [5]. Strength properties are a set of diagrams "stress-strain" with descending branches for certain values of the material heating temperature. Also this figure presents temperature strain of concrete and reinforcing steel.

To use extreme conditions the parameters based on valid standards of Ukraine for building structures heat resistance calculations are involved.

The values of the selected parameters are shown in Table. 3.

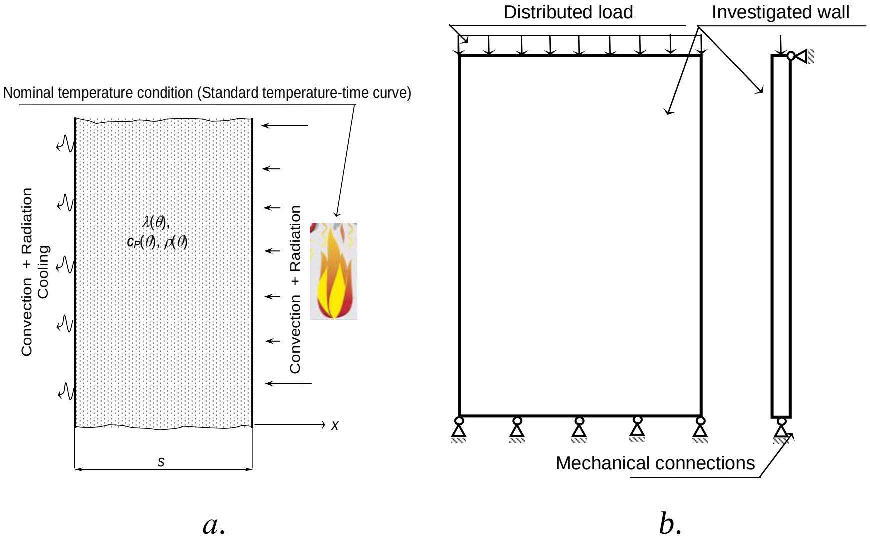


Fig. 5. Calculation scheme: for thermotechnical task(*a*); for static task (*b*).

Tab. 3. Extreme conditions parameters

Characteristic	Unit	Value	Source
Extreme conditions parameters of thermotechnical task			
Nominal thermal effect	Standard temperature conditions of fire		
Convection heat exchange coefficient on the heated surface	W/(m^2·K)	25	[4]
Convection heat exchange coefficient on the non- heated surface	W/(m^2·K)	6	[4]
Blackness degree	-	0.7	[4]
Stefan-Boltzmann constant	W/(m^2·K^4)	5.67·10^{-8}	[6]
Extreme conditions parameters of static task			
Current load	t/m^2	150	-
Poisson's constant	-	0,2	[4]

For the calculation network walls models were constructed, which look is shown in Fig. 6.

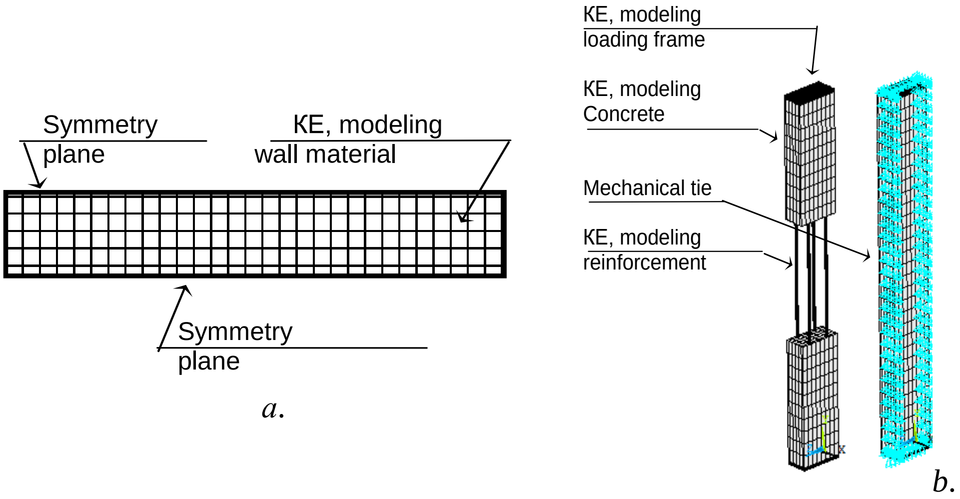
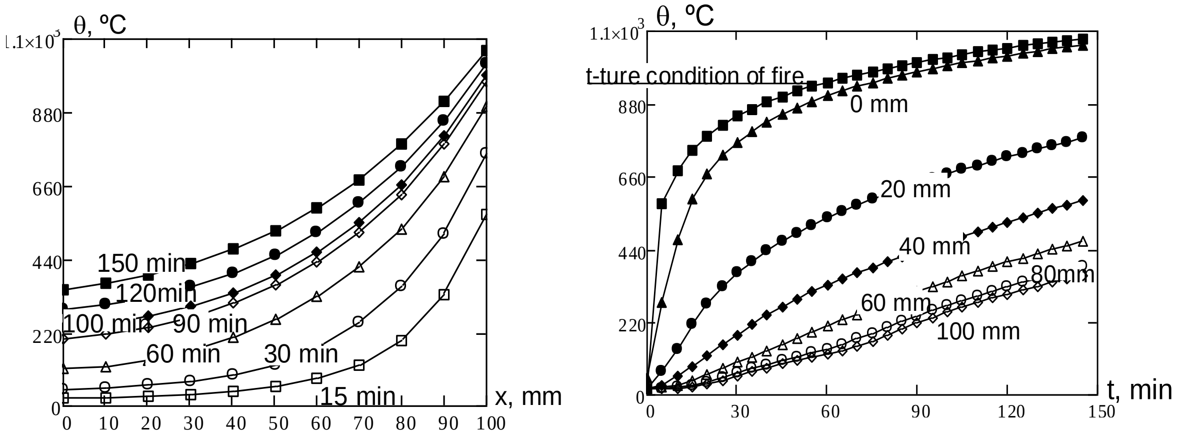


Fig. 6. Network models: for thermotechnical task (*a*); for static task (*b*).

For the network the fact that the network for the thermotechnical task according to the calculation scheme (see. Fig. 3) is undimensional and should be much thicker is taken into account/ Static task network should to be rougher and take into account local feature of inner layers adjacent to heated surface stronger heating. So it should also be thicker in these layers.

To reduce the amount of calculations a small fragment of the wall is considered, because the stress-strain state along the wall does not change. Fragment work in the whole wall is taken into account by setting the extreme conditions of symmetry on its sides. These conditions provided the unilateral establishment of appropriate mechanical ties. Blending temperatures in the nodal points is by linear interpolation.

As a result of the thermo technical task solving temperature distribution that shown in Fig. 7 is obtained.

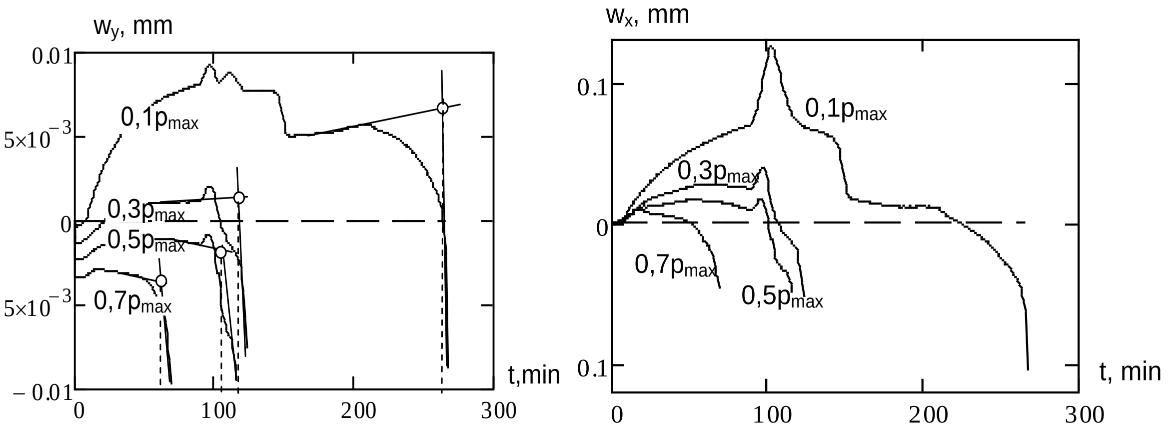


a. *b.*

Fig. 7. Results of the thermotechnical task solving: temperature distribution in the section of the wall (a); temperature conditions of the wall inner layers heating (b).

To solve the static task different levels of mechanical stress are examined. The value of destroying pressure on the wall was defined by calculation, which is 2100 t / m2. To study the load effect the load values are applied of a series 0,1·p_{max}, 0,3·p_{max}, 0,5·p_{max}, 0,7·p_{max}.

After the static task solving the graphics were obtained vertical displacements of the upper edge of the wall, and horizontal displacements of its center are obtained. The graphics are shown in Fig. 8.



a. *b.*

Fig. 8. Static task solving results: vertical displacements of the upper edge of the wall (*a*) horizontal displacements of the wall center (b).

According to the graphics initially the wall is bent toward the fire action while moving up its upper edge. At the final stage wall is aligned and the deflection almost disappears. At the stage of destruction bend occurs in the direction opposite the fire action. Thus for loads with magnitude $0{,}1p_{max}$, $0{,}3\ p_{max}$ top edge initially moves upwards and at some stage movement becomes positive, that the height of the wall increases. With the destruction the wall height again decreases with deflection increase in the direction opposite to the fire action. At higher loads, increase of thewall height is observed. This effect occurs because initially the layers of the fire action expand and thus the bend of walls and longitudinal movement of the upper edge upwards occurs. With further gradual warming walls of deeper layers expand, while after reaching a certain temperature warmed layers do not expand (see. Fig. 3), and therefore the deflection of the wall decreases. Due to the fact that more layers are heated more easily they deform and in the final stage, the deflection in the direction opposite to the fire occurs. The result of this pattern is wall buckling and its destruction.

The resulting graphics allow to get information about the state of the extreme condition of bearing capacity loss by comparing current values of displacement and velocities with maximum allowable, determined by formulas [2, 3]:

$$D = 0.01h = 32\ \text{mm};\ dD/dt = 3h/1000 = 9{,}6\ \text{mm/min}. \qquad (1)$$

The graphics analysis shows that with the criteria of (1) extreme conditionof bearing capacity loss does not occur. But a graph in Fig. 8 shows that at the final section the sharp deformation increase occurs, indicating the formation of local plastic deformation zone, which proves the extreme condition of bearing capacity loss. To determine the fire resistance the tangent method is used, described in [6]. Bytangents on areas of vertical displacement curves shown in Fig. 8 the fire resistance of the wall, subjected to mechanical loads with different values is determined. Dependence of fire resistance to the load capacity on the applied pressure shown in Fig. 9

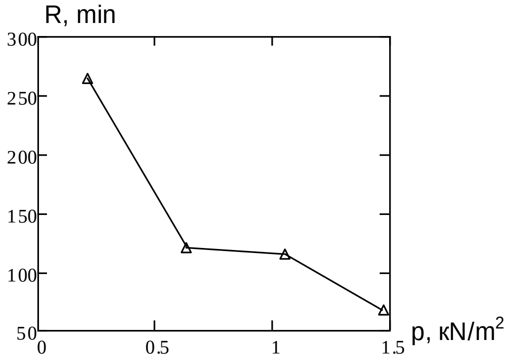


Fig. 9. Dependence of wall fire resistance on the applied pressure.

Results

In the connection with the research it can be concluded that:

1. Numerical researches of reinforced concrete walls conduct under the fire influence, with standard temperature conditions is conducted.

2. It is shown that the wall during the test initially bends toward the fire and then the fire changes direction of longitudinal bend passing the initial position of its neutral axis.

3. It is shown that the extreme condition of wall buckling is due to the formation of the plastic deformation zone due to longitudinal bending after passing the initial position of its neutral axis.

4. Dependence of fire resistance on the applied pressure to the wall is discovered. In the range of loads $0{,}3p_{max}$... $0{,}5\ p_{max}$ limit of fire resistance does not depend on the applied load.

Abstract

One of the condition of structure strength (due to building fire safety) is to assure its bearing capacity during the fire. The article informs on the stress-strain state parameters and the reinforced concrete wall destruction mechanism under the fire influence with the standard temperature conditions using finite elements method. On the basis of analysis conclusions have been formulated.

Badania nad wpływem ognia na ściany żelbetowe z wykorzystaniem metody elementów skończonych

Streszczenie

Jednym z warunków wytrzymałości konstrukcji ze względu na bezpieczeństwo pożarowe budynków jest zapewnienie jej nośności w trakcie pożaru. W artykule przedstawiono informacje na temat mechanizmu destrukcji ścian żelbetowych pod wpływem działania ognia dla standardowych warunków rozwoju pożaru przy użyciu metody elementów skończonych. Na podstawie przeprowadzonej analizy sformułowane zostały wnioski końcowe.

LITERATURA / BIBLIOGRAPHY

[1]. Fire protection. Fire safety of constructions. DBN V.1.1-7-2002 [Valid from 01.05.2003.]. - K .: Publishing house "Libra", 2003. - 87 p - (National Standard of Ukraine).

[2]. Building construction. Test methods for fire. General requirements. Fire safety. (ISO 834: 1975) ISO V.1.1-4-98 B *. [Valid from 28.10.1998.] - C .: Ukrarhbudinform, 2005. - 20 p - (National Standard of Ukraine).

[3]. ISO B V.1.1-19: 2007 Protection from fire. Load-bearing walls. Test method for fire. - K .: Ukrarhbudinform, 2008. 37 pp - (National Standard of Ukraine).

[4]. EN 1992-1-2:2004 Eurocode 2: Design of concrete structures Part 1-2: General rules - Structural fire design, Brussels, 2004.

[5]. S.V. Pozdeyev, *Development of an improved calculation method to determine the fire resistance of load-bearing concrete structures*. / Pozdeyev SV Levchenko AD // Scientific Bulletin of National Technical University "Lviv Polytechnic". - Lviv: National Technical University "Lviv Polytechnic". - 2011. - S. 264 - 269.

[6]. Milovanov AF, *Fire resistance of concrete structures* / AF Milovanov - M .: Stroyizdat, 1986. - 224 p.

[7]. Ruvalcaba AyalaF.R. *Mechanical properties and structural behavior of masonry at elevated temperatures*. A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy. – 2010. – 294 p.