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Research paper

The Fire Resistance of Monolithic Floor Slabs of Buildings and for Various Exposure Areas of the Fire

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Abstract

Structural design of buildings is currently performed on operational loads without taking into account the possible impact of fire. However, as practice has shown, fires often occur in both residential and public buildings. In this case, there is a strong heating of the supporting structures, due to which there is a change in their mechanical properties, and they behave differently from the design loads before the fire. The article considers the impact of fire on the internal forces and deflections of monolithic slabs of buildings.

Keywords: Fire Resistance, Strength, Mechanical Properties of Concrete, Bending Moments, Finite Element Method, Deflections.

1. Introduction

Fire resistance – the ability of structures to resist the fire impact for a given time. According to the Russian design standards [2, p.2], the calculation of the fire resistance of structures requires their verification of the limiting States: the loss of bearing capacity R, the loss of integrity, loss of heat insulation ability of the first degree of fire resistance of the Building, for which the required time of the fire is 120 minutes, which corresponds to the parameter R120. The studies considered the parameters of the ceilings under the influence of fire only on the bearing capacity. The purpose of the calculations was to check the structures for their collapse or the occurrence of an unacceptable deflection. The loss of insulating capacity I was not considered due to the fact that according to the recommendations [1, p. 11] the thickness of monolithic slabs is not less than 160 mm, and according to the norms [2, p. 12] it was found that already at such a thickness the violation of thermal insulation can occur at a fire time of 260 minutes, which exceeds the limit of fire resistance on the bearing capacity In calculations it was also accepted that loss of integrity of overlappings E within 120 minutes of the fire does not occur.

During the research, a multi-storey building was considered, the typical overlap of which is shown in Fig.1. In the calculations, the thickness of the overlap was taken 200 mm.

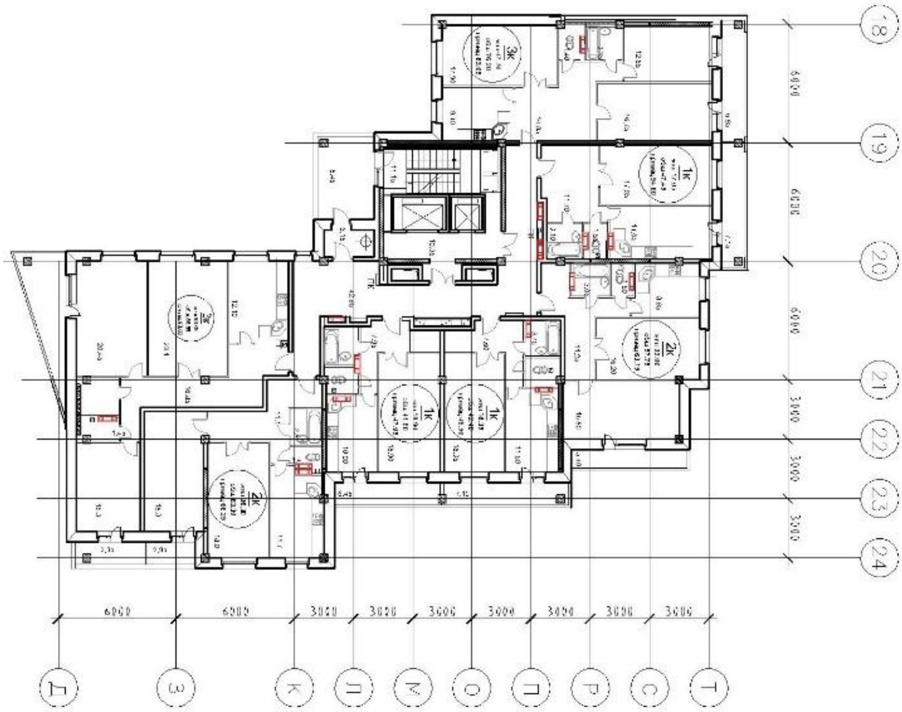

Figure. 1: Typical floor plan of the building

The calculations of the building were carried out by the finite element method using the program complex "LIRA-CAD 2018". Loads on the building were: own weight of structures; constant loads from floors and coatings; temporary payloads; wind load. For rice. 2. the finite element model of the building under consideration is shown. For floor slabs fire impact of the fire was set either on one side within one floor slab of a building, or on two adjacent floors with fire impact on both sides of the floor slab.

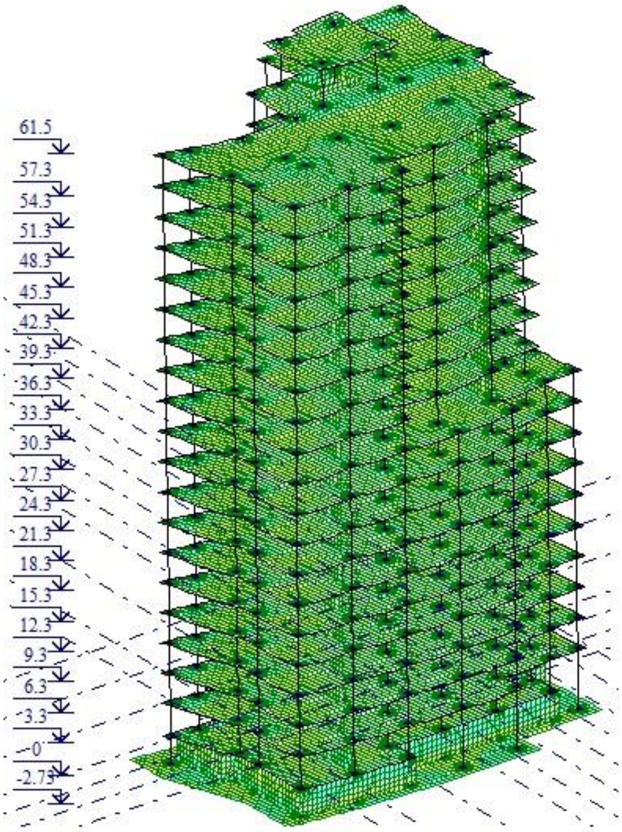

Figure. 2: Finite element model of the building in PC "LIRA-CAD 2018»

During a fire, concrete structures are subjected to high-temperature effects, which change the mechanical characteristics of concrete and reinforcement [4, p. 127]. Thus, the deformation modulus of concrete under temperature action is determined by the dependence [2, c. 6]:

$$E_{bt} = E_b \beta_b, \quad (1)$$

where - β_b – is the coefficient that takes into account the increase in temperature under short-term fire exposure.

At the same time, if the impact of the fire occurs only on one side of the overlap, the deformation modules of the concrete top and bottom of the overlap will be different, that is, the deformation module for the thickness of the ceilings will change. The modulus of deformation of concrete will also vary in thickness and fire impact on both sides of the slab-top and bottom. In view of this, to determine the deformation modulus of concrete for the entire calculated section of the plate it was divided into layers, and for each layer its deformation modulus was determined by the formula (1) at different time of fire exposure (30, 60 and 90 minutes), in which the graphs shown in Fig. 3, the temperature of the considered layer of concrete slab was determined [2, p. 51].

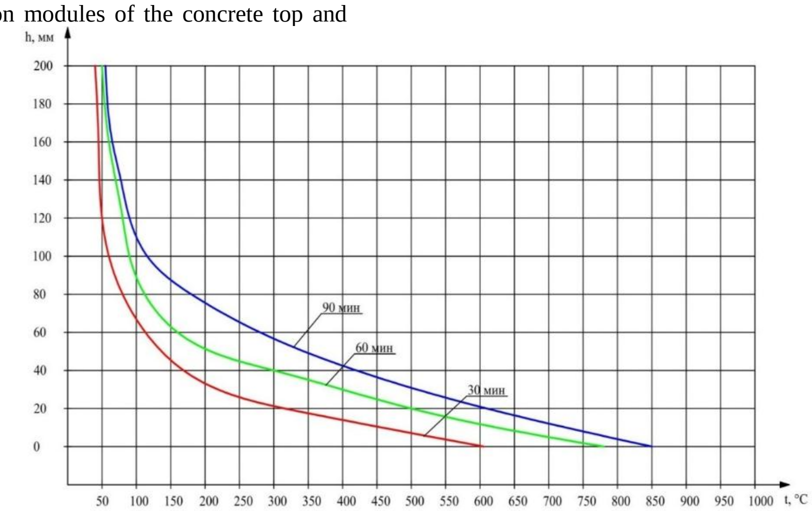

Figure 3: The temperature of the heating of heavy concrete with silicate aggregate in the slab thickness of 200 mm with one-sided fire exposure

To determine the required number of layers broken down by the thickness of the plate, an analysis of the convergence of the results in the calculation of the average deformation modulus, given in the table. 1, compiled for an example of the heating temperature of 600C under fire action on one side of the slab. When determining the deformation modulus of concrete E_{bt} plate thickness was divided into 1, 2 and 4 layers, which were determined by the values of the heating temperature and the coefficients β_b. After that, the mean values of the concrete deformation modulus E_{bt} over the cross section were determined.

Table 1: The values of the deformation modulus of concrete for the slab thickness of 200 mm of heavy concrete with silicate aggregate, when impacted by fire, on the one hand, a duration of 60 minutes

The thickness of the layers of the plate	Temperature, t^0C	β_b	E_{bt}, MPa	The average value of modulus of deformation E_{bt} when the number of sectors split according to the thickness of the plate, MPa		
				1	2	4
0	770	0,065	1950	21764	22380	22736
20	500	0,3	9000			
40	300	0,5	15000			
60	160	0,63	18900			
80	100	0,87	26100			
100	85	0,9	27000			
120	75	0,914	27420			
140	65	0,928	27840			
160	55	0,942	28260			
180	45	0,956	28680			
200	35	0,975	29250			

As can be seen from table 1, the average values of the deformation modulus at different breakdown of the slab into layers quickly converge, and already when broken into two layers, the difference with the deformation modulus when broken into 4 layers is 1.56%. For calculation of slabs subjected to fire effects in the calculations with use of PC "LIRA-SAPR 2018" in this case was adopted by the modulus of deformation E_b = 22736 MPa. Similarly were determined the average modulus of deformation E_b when impacted by fire on the slab from two sides. The calculation results are given in table. 2. As can be seen from table 2, when the fire impact on the floor plate on both sides-top and bottom, the deformation modulus of concrete is greatly reduced and is 0.6...0.7 of the modulus of deformation under fire action on the one hand. In view of this, the rigidity of the cross-sections of the slab is reduced and there is a risk of unacceptable deformations.

Table 2: The values of the deformation modulus of concrete for the slab thickness of 200 mm of heavy concrete with silicate aggregate, when impacted by fire from two sides (top and bottom), with a duration of 60 minutes

Thickness	Temperature, t^0C	β_b	E_{bt}, MPa	The average value of modulus of deformation E_{bt} the four sections of the partition plate across the thickness, MPa
0	770	0,065	1950	14920
20	500	0,3	9000	
40	300	0,5	15000	
60	220	0,66	19800	
80	180	0,733	21900	
100	150	0,775	23250	
120	180	0,733	21900	
140	220	0,66	19800	
160	300	0,5	15000	
180	500	0,3	9000	
200	770	0,065	1950	

In table. 3 the comparison of internal forces and deflections in the floor slab under operating loads before the fire with the results of calculations under fire impact within one floor and two adjacent floors is given.

Table 3: Internal forces and deflections in the floor plate under operating loads before the fire, under fire impact

Internal forces and deflections	Normal operating conditions	Fire exposure time (minutes)	
		60	120
In case of fire impact on one side of the floor slab			
Mx (кН*м)/м	21.4	21.9	22.4
My (кН*м)/м	22.1	22.7	23.3
ʃ (мм)	3,4	3,97	4,43
When impacted by fire from two sides of the slab			
Mx (кН*м)/м	21.4	29,9	46,3
My (кН*м)/м	22.1	31,6	47,8
ʃ (мм)	3,4	6,6	11,6

From table. 3 it follows that the fire action bending moments and deflections in the slab increase. For rice. 4...6 shows graphs of deflections and bending moments in the slab under fire.

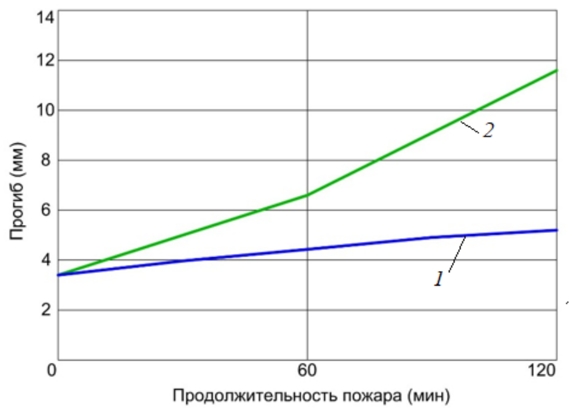

Figure 4: The deflection of the slab during unilateral (1) bilateral and (2) the fire activity

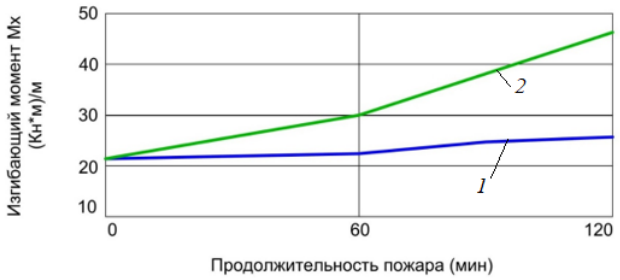

Figure. 5: Bending moment MX in the floor plate at one-way (1) and two-way (2) fire action

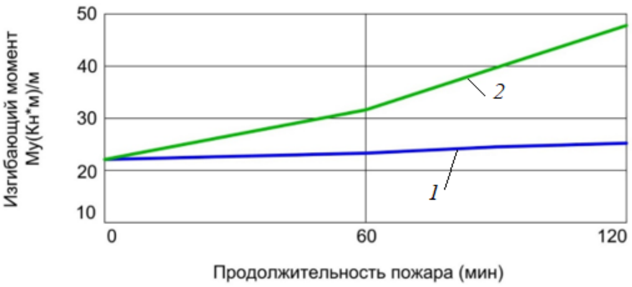

Figure. 6: The bending moment Mu in the slab during unilateral (1) bilateral and (2) the fire activity

As can be seen from graphs 4...6, during fire exposure on slabs above and below there is a significant increase in deflections, 241%, and the bending moments, Mx for 116,3% a My on 116,2% in comparison with normal structures, while, when impacted by fire from one side of the bending moments and deflections increase the deflection of 52.9%, the bending moment Mx on 20,1%, the bending momentMx is 14%.

2. Conclusion

Consequently, the spread of fire in the vertical direction on the floors of the building is much more dangerous than its spread to the premises within one floor. Therefore, in the design and construction it is necessary to take measures to prevent the spread of fire especially in the height of the building. This requires the use of non-combustible materials, closing all technological holes, equipping buildings with automatic fire extinguishing means.

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