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POŽARNA OTPORNOST SLOBODNO OSLONJENIH AB PLOČA NOSIVIH U JEDNOM PRAVCU

S-13

Rezime:

U radu su prikazani numerički rezultati požarne otpornosti slobodno oslonjenih AB ploča, nosivih u jednom pravcu. Analiziran je uticaj debljine zaštitnog sloja, procenta armiranja, raspona i debljine ploče. Požarna otpornost ploča je definisana primenom 'metode granične nosivosti'. Ova savremena metoda koja se koristi za proračun konstrukcija, koristi se i za definisanje požarne otpornosti. Prezentirani su i upoređeni rezultati dobiveni primenom 'uprošćene' proračunske metode, opisane u Eurocodu 2 dio 1.2, i primenom numeričkog programa FIRE.

Ključne reči: AB ploča, požarna otpornost, zaštitni betonski sloj, procent armiranja

FIRE RESISTANCE OF ONE-WAY SIMPLY SUPPORTED REINFORCED CONCRETE SLABS

Summary:

This paper presents the numerically achieved results for the fire resistance of one-way simply supported reinforced concrete slabs. The effects of: concrete cover thickness, reinforcement ratio, slab span and thickness were analyzed. The fire resistance of the RC slabs was defined by 'ultimate strength design' criteria as used in all modern concrete design codes. Results obtained from 'simplified' calculation method, described in Eurocode 2 part 1.2, and by using the software FIRE are presented and compared in this paper.

Key words: RC slab, fire resistance, concrete cover thickness, steel ratio

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1 INTRODUCTION

The resistance of building members to the effects of fire is an important part of any structural and fire safety design. Floor slabs, as horizontal elements, have a very important role in providing bearing capacity, usability and stability of the building as a whole. Their proper selection and design, when they are exposed to different types of loads (mainly: permanent and variable), should provide stable and safe structure during the exploitation period.

In case of fire floor slabs do not have only **load bearing function**. In most cases they are used as elements for separating the fire compartment. Where compartmentition is required, the elements forming the boundaries of the fire compartment, including joints, shall be designed and constructed in such a way that they maintain their separating function during the relevant fire exposure [1]. This shall ensure, where relevant, that **integrity failure** does not occur, **insulation failure** does not occur, thermal radiation from the unexposed side is limited.

The criterion **Integrity (E)** expresses the ability of the separating element of the building construction, when exposed to fire on one side, to prevent the passage of flames and hot gases through it and to prevent the occurrence of flames on the unexposed side.

The criterion **Insulation (I)** expresses the ability of the separating element of the building construction when exposed to fire on one side, to restrict the temperature rise of the unexposed face below specified levels.

The criterion **Load bearing function (R)** expresses the ability of the structure or the member to sustain specified actions during the relevant fire, according to defined criteria. Criterion "I" may be assumed to be satisfied where the average temperature rise over the whole of the non-exposed surface is limited to 140 K, and the maximum temperature rise at any point of that surface does not exceed 180 K [1].

Does the floor structure meet the required fire resistance criteria mainly depends on: mechanical and thermal characteristics of the materials used for the construction; initial loading level; support conditions; dimensions of the cross section; steel ratio; concrete cover thickness and fire scenario.

The fire resistance of the massive simply supported reinforced concrete slabs which have load bearing capacity only in one direction with different thickness and spans, used for the multi story residential buildings, is analyzed in this paper.

A durable structure shall meet the requirements of serviceability, strength and stability throughout its design working life, without significant loss of utility or excessive unforeseen maintenance. In fire conditions, as a result of a large number of real fire tests and corresponding numerical analyzes, it was found out that the moment of failure of the floor structure is always followed by significant deformation (deflection). If the structure is close to the limit state, after the cooling phase the residual deflections are so great that it cannot be used without significant rehabilitation. For these reasons, during the fire action, the deformation (deflection) of the slab is limited to prescribed value. According to the ISO standard, this limit value is L/30 (L is the span of the slab) [3].

This paper presents the numerically achieved results for the fire resistance of nine solid RC slabs with different span and thickness. For comparison, all slabs were analysed as simply supported slabs and were exposed to ISO standard fire from the bottom side, as most usual fire scenario. The RC slabs were constructed without thermal insolation at the bottom side of the slabs. Based on the numerically achieved results, certain conclusions that can be useful for metching the prescribed fire resistance of these type of floor structures were obtained.

2 FIRE RESISTANCE OF ONE-WAY SIMPLY SUPPORTED RC SLABS

The computer program FIRE (Cvetkovska, Ss. Cyril and Methodius University in Skopje, Macedonia), based on Finite Element Method, was used for the fire resistance analysis of the simply supported RC slabs treated in this paper. This program is capable of conducting the nonlinear and transient heat flow analysis and nonlinear stress-strain response associated with fire.

The program FIRE [4] consists of two modules. The modulus FIRE-T solves the governing differential equation of heat transfer in conduction by taking into account the fire boundary conditions modeled in terms of both convective and radiating heat transfer mechanisms. The response of reinforced concrete elements and plane frame structures exposed to fire is predicted by modulus FIRE-S. This modulus accounts for: dimensional changes caused by temperature differences, changes in mechanical properties of materials with changes in temperature, degradation of sections by cracking and/or crushing and acceleration of shrinkage and creep with an increase of temperature.

A 'simplified' calculation method described in Eurocode 2 [1] was also used for the fire resistance analysis of the simply supported RC slabs treated in this paper. Wickström's formula is used to calculate the reinforcing temperature.

2.1 SIMPLIFIED CALCULATION METHOD

There are simplified methods for calculation the fire resistance of one-way slabs. Their application is possible only for simply supported and continuous slabs exposed to fire only from the bottom side.

The design procedure for concrete simply supported slabs assumes the following: concrete has no tensile strength and the parabolic compressive block in concrete can be approximated by an equivalent rectangle, which can be seen in (Figure 1). It is also assumed that the compressive block does not rich elevated temperatures which causes reduction in material properties and that the flexural capacity is solely a function of the temperature of the reinforcing steel.

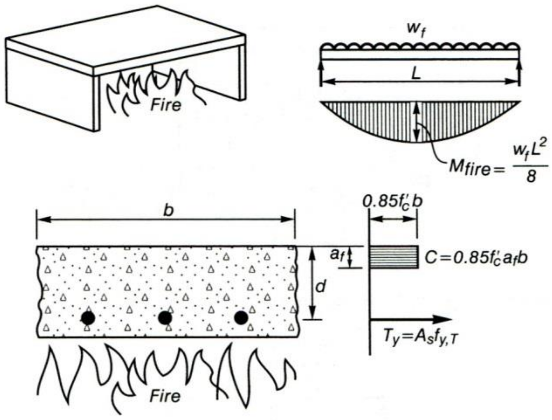

Figure 1 – One-way simply supported RC slab exposed to fire from the bottom side

There is no possibility of moment redistribution in case of simply supported slabs. The design equation for a member subjected to a bending moment M_{fire} is:

$$M_{fire} \leq M_{u,f}$$

The flexural capacity under fire conditions is given by:

$$M_{u,f} = A_s f_{y,T} (d - a_f / 2)$$

where:

A_s - the area of the reinforcing steel,

$f_{y,T}$ - the yield stress of the reinforcing steel, temperature reduced ($f_{y,T} = k_{y,T} f_y$),

d - the effective depth of the cross section (distance from the extreme compressed fiber to the centroid of the reinforcing steel),

a_f - the depth of the rectangular stress block, reduced by fire and given by:

$$a_f = \frac{A_s f_{y,T}}{0.85 f_{cd} b}$$

where:

f_{cd} - the design value of compressive strength of the concrete at room temperature,

b - the width of the slab strip.

Most of countries in Europe apply ISO 834 Standard fire curve, given by expression:

$$T_f = 20 + 345 \, log(8t + 1)$$

Wickström's formula, which is used to calculate the reinforcement temperature, is given by expressions:

- Surface temperature:

$$T_w = \left[1 - 0.616 t_h^{-0.88}\right] T_f$$

- Concrete temperature at depth *'c_e'*:

$$T_c = \left[0.18 ln\left(\frac{t_h}{c_e^2}\right) - 0.81\right] T_w$$

- Steel temperature

$$T_s = T_c$$

3 RC SLAB ANALYSIS

The following parameters, characteristics and conditions were assumed:

- The slabs were exposed to ISO 834 Standard fire only from the bottom side,
- Separate 1 m wide strips were analysed,
- The temperature dependent physical and mechanical properties of the siliceous aggregate concrete (compressive strength f_{ck}=30Mpa) and the reinforcement (yield strength f_{yk}=400Mpa) were assumed according to EC2, part 1-2,
- Dead load G_1=1.5 kN/m^2 (excluding self weight),
- Live load Q=4.0 kN/m^2, reduction factor in case of fire $\Psi_{2,1}$=0.6 (for category C)

All data about the slabs geometry and the intensities of the dead and live loads are given in Table 1.

Table 1 – Slab geometry and load intensity

Slab	Span (m)	Thickness (cm)	Concrete cover (cm)	G_{slab} (kN/m^2)	G_1 (kN/m^2)	Q_1 (kN/m^2)	$p_{slab,cold}$ (kN/m^2)	$p_{slab,fire}$ (kN/m^2)
S_1	4	16	2.5	4	1.5	4	13.425	7.900
S_2	4	16	3	4	1.5	4	13.425	7.900
S_3	4	16	3.5	4	1.5	4	13.425	7.900
S_4	4	17	2.5	4.25	1.5	4	13.763	8.150
S_5	4	18	2.5	4.5	1.5	4	14.100	8.400
S_6	5	16	2.5	4	1.5	4	13.425	7.900
S_7	5	17	2.5	4.25	1.5	4	13.763	8.150
S_8	5	18	2.5	4.5	1.5	4	14.100	8.400
S_9	6	16	2.5	4	1.5	4	13.425	7.900
S_{10}	6	17	2.5	4.25	1.5	4	13.763	8.150
S_{11}	6	18	2.5	4.5	1.5	4	14.100	8.400

As first case study the criterion **Load bearing function (R)** was analysed. The fire resistance for all case studies is given in Table 2.

Table 2 – Fire resistance of RC slabs

Slab	Steel ratio (%)	Fire resistance (min) simplified calculation method	Fire resistance (min) program FIRE
S_1	0.392	124.13	122.4
S_2	0.415	158.68	151.8
S_3	0.441	190.78	184.2
S_4	0.369	128.06	130.8
S_5	0.348	131.45	133.2
S_6	0.706	140.18	138.6
S_7	0.665	143.69	141.6
S_8	0.628	146.70	142.2
S_9	1.068	147.29	148.2
S_{10}	1.005	151.05	151.2
S_{11}	0.950	155.05	153

The results show the effect of the concrete cover thickness, the span and thickness and the steel ratio on the fire resistance of the RC slabs. The results obtained by simplified calculation method and the program FIRE are presented and compared. The results for the slabs S_1, S_2 and S_3 have shown that the concrete cover thickness has significant effect on the fire resistance of the RC slabs. In case when the concrete cover thickness is increased, the fire resistance of slab is increased too. From sets S_1,S_4,S_5; S_6,S_7,S_8 and S_9,S_{10},S_{11} it could be concluded that in case when the slab thickness is increased, the fire resistance of the slabs is increased too. In same time, the positive effect of the slab thickness on the criterion **Insulation (I)** is shown in Figure (9). For higher values of the slab thickness the temperature on the unexposed surface of the slab was less.

All the results for the analysed slabs are presented in Figures (2-8).

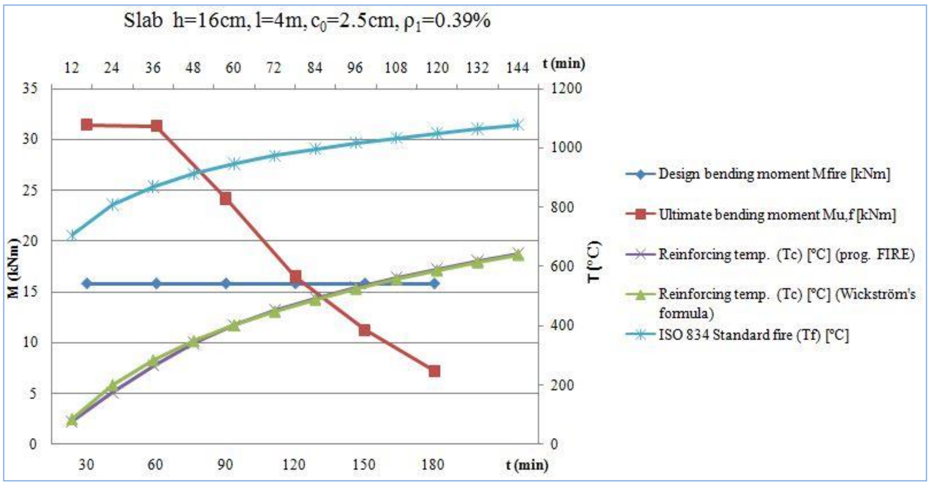

Figure 2 – Fire resistance of one-way simply supported RC slab with 4m span, 16cm thickness and 2.5cm concrete cover thickness

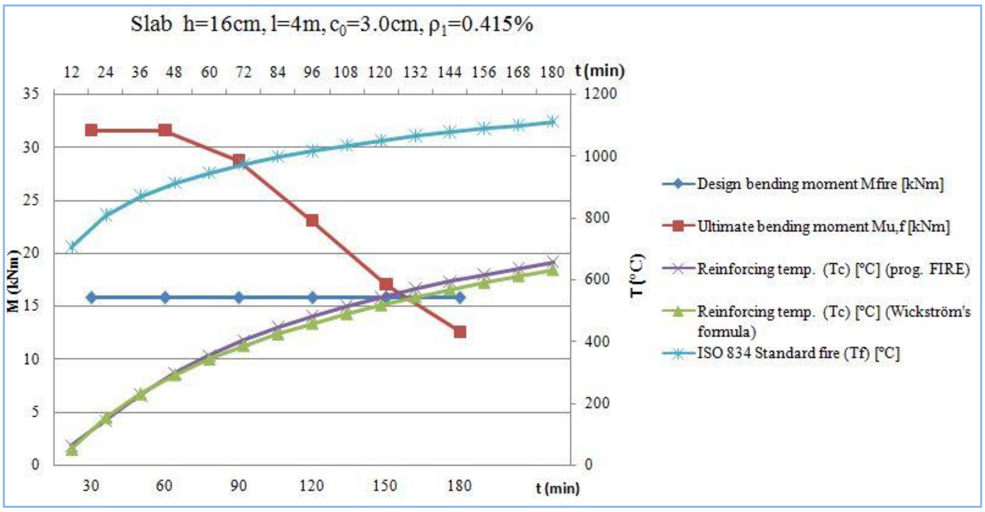

Figure 3 – Fire resistance of one-way simply supported RC slab with 4m span, 16cm thickness and 3.0cm concrete cover thickness

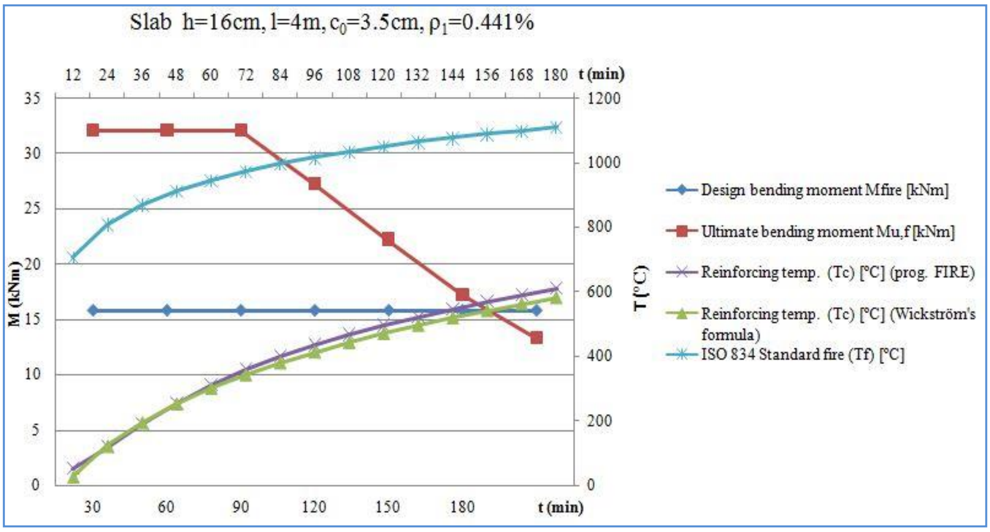

Figure 4 – Fire resistance of one-way simply supported RC slab with 4m span, 16cm thickness and 3.5cm concrete cover thickness

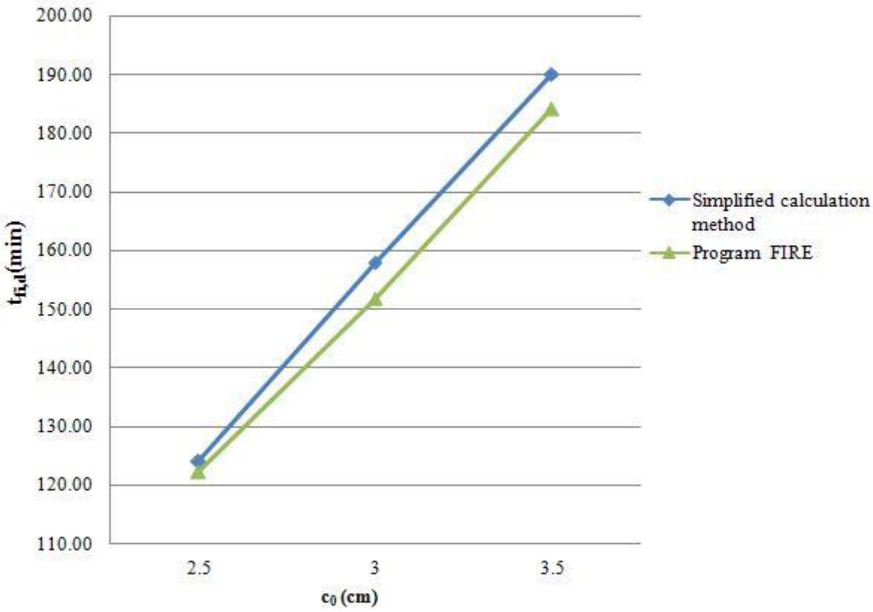

Figure 5 – The effect of concrete cover thickness on fire resistance of one-way simply supported RC slab, 4m span, 16cm thickness and comparision of the results obtained with the simplified calculation method and the program FIRE

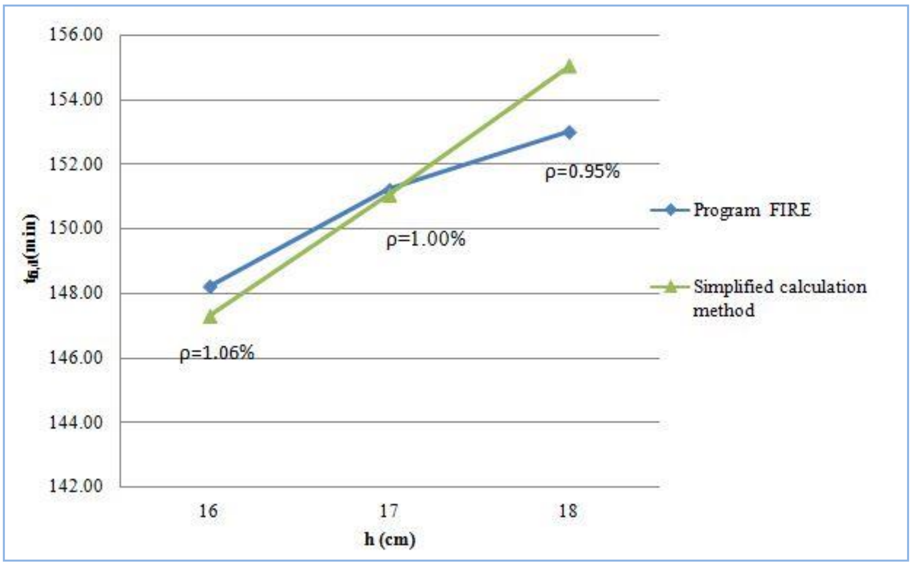

Figure 6 – Fire resistance of one-way simply supported RC slab, 5m span, 2.5cm concrete cover thickness, for different slab thicknesses, and comparision of the results obtained with the simplified calculation method and the program FIRE

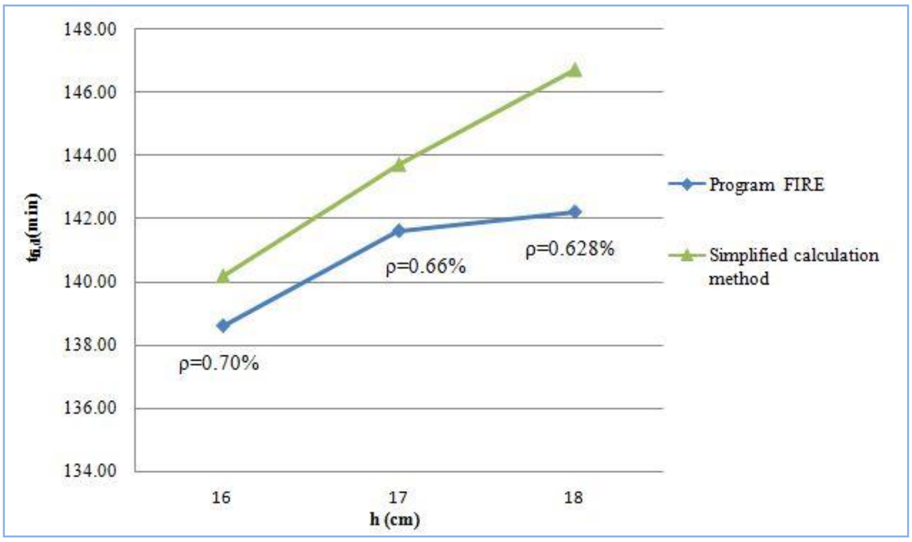

Figure 7 – Fire resistance of one-way simply supported RC slab , 6m span and 2.5cm concrete cover thickness, for different slab thicknesses, and comparision of the results obtained with the simplified calculation method and the program FIRE

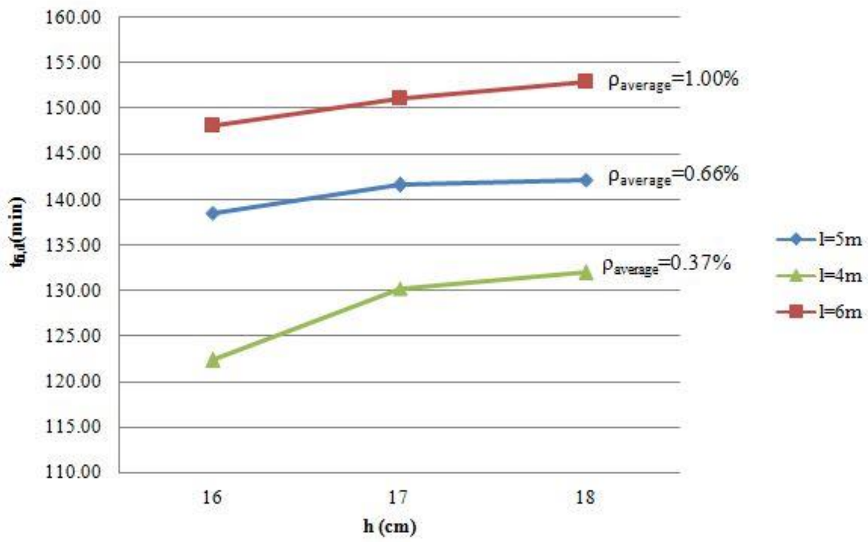

Figure 8 – Relation ‘slab span-fire resistance’ of one-way simply supported RC slab

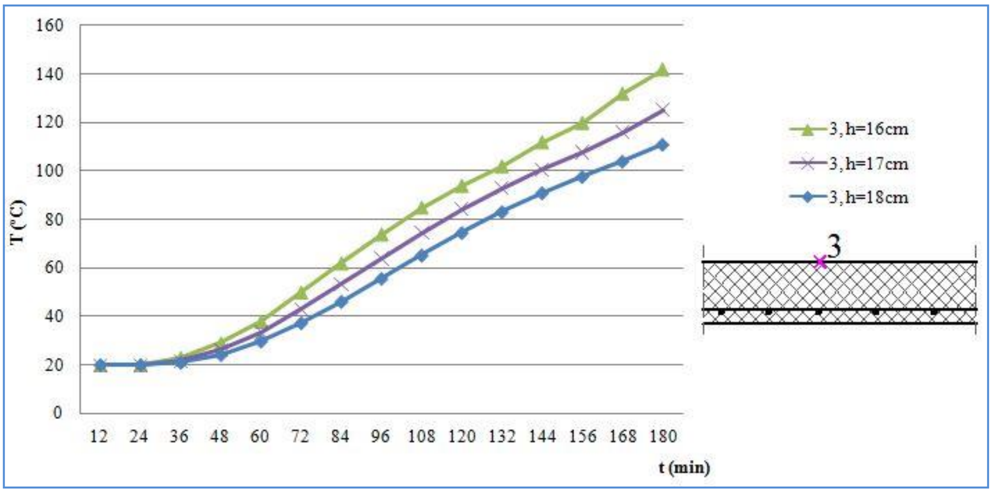

Figure 9 –The effect of slab thickness on criterion I, slab with 4m span and 2.5cm concrete cover thickness

4 CONCLUSIONS

The analysis presented in this paper show that concrete cover thickness and reinforcement ratio have positive effect on increasing the fire resistance of RC slabs. By increasing the slab thickness the fire resistance of the RC slabs is increased too.

The simplified calculation method (EN 1992-1-2, 2004), presented in this paper, is capable for defining the fire resistance of one-way simply supported reinforced concrete slab, exposed to fire from the bottom side. This method is simple for implementation, useful for single members and provides satisfactory results.

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UTICAJ POŽARNOG SCENARIJA NA POŽARNU OTPORNOST RAMOVSKIH KONSTRUKCIJA

Rezime:

Razumeti bitne karakteristike i ponašanje armiranobetonskih ramovskih konstrukcija u požaru, ovisno od požarnog scenarija, je vrlo važno za pravilno projektovanje istih. Ovaj rad prikazuje uticaj četiri različitih požarnih scenarija na požarnu otpornost trobrodnog i dvospratnog armiranobetonskog rama. Rezultati numericke analize: temperatura u presecima pojedinih elemenata konstrukcije, požarna otpornost konstrukcije, momente savijanja i deformacija konstrukcije, dobijene su kroz termičku i mehaničku analizu primenom kompjuterskog programa SAFIR.

Ključne reči: požarna otpornost, požarno scenario, temperatura, deformacija

FIRE SCENARIO INFLUENCE ON FIRE RESTIANCE OF RC FRAME

Summary:

Understanding the performance and the response of the reinforced concrete frame structures in fires, depending on the fire scenario, is important for structural fire design. Four different fire scenarios of standard fire exposure in a three bay two storey RC frame are analyzed and the results for the: fire resistance, bending moments and deformations are presented and discussed. The temperature distribution within the structural elements and the structural behaviour due to thermo-mechanical loading were calculated in the SAFIR2014 computer program. Worst fire scenario for the frame is when the fire is assumed in the whole second floor.

Key words: fire resistance, fire scenario, temperature, deformation

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