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Abstract: The last decade has been characterized by construction of multi-storey buildings in almost all cities of Kosovo, with the storey-height ranging from B+G+4 to B+G+11 and even B+G+15, which means that they need to be subjected to the revision of the main project,including things be verified for the effect of fire.

This paper aims to illustrate the use of EC regulations for the verification of *reinforced concrete structures* under effect of fire, respectively:

EN 1991-2-2 Basis of design and actions on structures. Part-2.2: Actions on structures exposed to fire and EN 1992-1-2:2004 Design of concrete structures- part -1-2: Structural fire design.

In this regard, we will review the residential and business object B+G+11, respectively the complex called "KULLAT" in Mitrovica, the safety assessment of reinforced concrete structures in case of fire The analysis of certain parts of the structures - beams and columns by applying the tabular method and analysis of beams with the application of simplified calculation method will be shown.

Keywords: Fire calculation, Tabular calculation, simplified calculation method, Cross-section resistance

1. Introduction

The comprehensive analysis of reinforced concrete structures under the specified fire scenario includes thermal analysis (determination of temperature distribution within each point of structural elements) and mechanical analysis (evaluation of structural response to determined temperature fields). In order to carry out these analyses, it is necessary to possess detailed information as to numerous material properties (physical, thermal, mechanical –both for structural concrete and for reinforcing steel) which are the functions of temperature [1]

In this regard, we will review the safety assessment of reinforced concrete structures in case of fire for the residential and business object B+G+11, respectively the complex called "KULLAT" whitch c ontains a basement 2.6 m high, the ground floor 3.9 m high and 11 floors 2.9 m high. In case of an eventual risk of fire, the building height for evacuation is: 3.9 + 11x2.9 = 35.8m. The surface of facade openings: windows and balcony doors per one storey is :48,405 m^2 . The analysis of certain parts of the structures - beams and columns by applying the tabular method and analysis of beams with the application of simplified calculation method will be shown. Than only the object in a surface of storey 491.84 m2 will be reviewed.

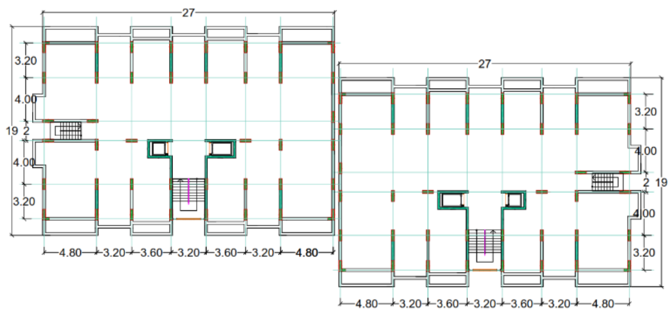

Fig1. The base of the characteristic storey of the object B+G+11

2. Values – limit state and load combination

2.1 Equation of the value – limit state

The equation of the limit state is expressed by:

$$R_{fi,d,t} \geq E_{fi,d,t} \qquad \textbf{(1)}$$

Where:

$R_{fi,d,t}$ design resistance in the fire situation, at time t.

$E_{fi,d,t}$ design effect of actions in the fire situation, at time t. [2]

2.2 Permanent situation for normal temperature design

Taking into account only permanent and temporal loads, the following shall apply for the calculation permanent situation:

$$\sum_{j\geq 1} \gamma_{G,j} \cdot G_{kj}) + \gamma_{Q,1} \cdot Q_{k1}; \quad = 1.35 \cdot g_k + 1.5 \cdot q_k \qquad \textbf{(2)}$$

G_{kj}, Q_{k1} characteristic values of permanent and imposed loads

$\gamma_{G,j}, \gamma_Q$ partial factor for permanent actions and for imposed loads

Analysis of permanent loads:

- Reinforced concrete slabs 0.2x25=5.0Kn/m2x(4.8/2+3.2/2) =20.0 Kn/m'
- Beams 0.35x0.25x25= 2.188 Kn/m'
- Floor 1.5 Kn/m2 x(4.8/2+3.2/2) = 6.0 Kn/m'
- Walls 4x2.7= 10,8 Kn/m'

gk=38,99 Kn/m'

Live load:qk1=5.0x((4.8/2+3.2/2)=20 Kn/m', qk2=2.0x((4.8/2+3.2/2)=8 Kn/m'

The dimension of internal beams is 25/35 cm, while the dimension of perimetric beams is 25/50 cm. The beams are reinforced as shown in the fig 2. in the bottom area with 3 bars Rϕ14 mm and stirrups Rϕ8 mm /20/10 cm.

The minimum cover is 2 cm so that the distance from the bottom of the beam to the axis of the bars is:20+8+0,5 · 14=35 mm.

The dimensions of columns are 25/100 cm, which are reinforced as shown in the fig. 2. with 10R□20 mm +4 R□16 mm+2 R□12 mm in section "3-3" and with 14 R□16 mm+2 R□12mm in section "4-4".

The minimum cover is 2 cm, so the distance from the bottom of the column to the axis of the bars in fig.2 section "3-3"will be: 20+8+0,5 · 20=38 mm

While for the column in the section "4-4"will be: 20+8+0,5 · 16=36 mm

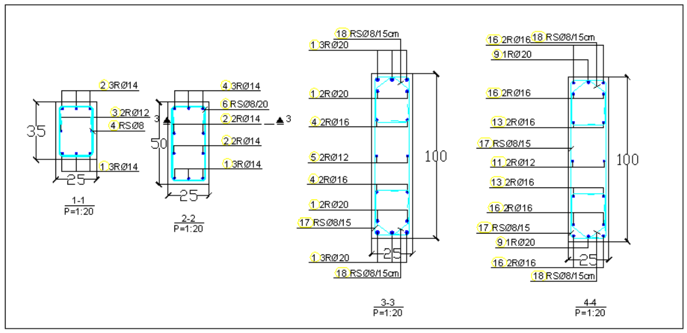

Fig.2. Cross-sections of the beams and columns

2.3 Accidental situation in fire situation

Having into consideration only one temporal load, respectively the exploitative one, the combination for the accidental calculation situation is expressed by:

$$\sum_{j\geq 1}(G_{kj})+ (\psi_{11} \text{ or } \psi_{2,1}) \cdot Q_{k1} +A_d \tag{3}$$

G_{kj}, Q_{k1} characteristic values for the permanent and temporal loads

γ, γ_Q partial safety factors for permanent actions in the accidental situation

$\psi_{11}, \psi_{2,1}$ combination factors for buildings

A_d design value of the accidental action (in this case actions caused by fire)

Expressed wth:

$$\xi=Q_{k,1}/G_k \tag{4}$$

and calculate the reduction factor η_{fi} which represents the connection between the calculation value of the effect of fire and calculation value of the effects during normal temperatures.

$$\eta_{fi} = \frac{G_k+\psi_{11} \cdot Q_{k1}}{\gamma_G G_k+\gamma_{Q1} \cdot Q_{k1}} = \frac{(\gamma_{GA}+\psi_{11} \cdot \xi_1)}{(\gamma_G+\gamma_Q \cdot \xi_1)} =0{,}59 \tag{5}$$

$$\text{For } \psi_{1,1=0,5}, \ \xi_2=0.2 \quad \text{we have: } \eta_{fi}=0.666 \tag{6}$$

$$\text{For } \psi_{2,1=0,3}, \ \xi_{1=0.51} \text{ we have: } \quad \eta_{fi}=0{,}54, \ \xi_2=0.2 \quad \eta_{fi}=0.64 \tag{7}$$

3. Fire calculation

3.1 Equivalent time of fire exposure –(III class of fire load)

The equivalent time of fire exposure is the neccesary time for the fire that follows the temperature-time curve to produce the same temperature in the element just like a real fire.The equivalent time of exposure to fire is determined according to:

$$t_{e,d}=q_{f,d} \cdot k_b \cdot w_f \quad [\text{min}] \tag{8}$$

which is:

$q_{f,d}$ is the design fire load density A_f according to annex E

k_b conversion factor dependent on the thermal characteristics of the circuit

w_f ventilation factor

where $$q_{f,d} =\gamma_q \cdot \gamma_n \cdot q_{f,k} \tag{9}$$

where is:

γ_q safety factor that depends on the consequences of the destruction of the structure and impact of the fire taken $\gamma_{q=1.5}$ from the table E.1 in the annex E of EN 1991-1-2

γ_n factor that takes into account the active protective measures against fire, verified firefighting equipments is expressed by $\gamma_{n=0.6}$
$q_{f,k}$ the value of the characteristic density of the fire load in the compartment unit on the assumption that it is III class fire load may be taken 1000 MJ/m^2

namely $$q_{f,d} = 1.5 \cdot 0.6 \cdot 1000 = 900 \text{ MJ/m}^2 \quad \textbf{(10)}$$

If the thermal characteristics of the environment/circuit were not implemented in details, we take k_b=0.07

$$w_f=(6.0/H)^{0.3}\,[0.62+90(0.4-\alpha_v)]^4/(1+bv\cdot \alpha_h)]>0.5 \quad \textbf{(11)}$$
where :
$$\alpha_{v=}A_v/A_f \quad \textbf{(12)}$$

with limits: $0.020<\alpha_v<0.20$; α_v=48,405 /491.84=0,098
$\alpha_{h=}A_h/A_f$ ratio of surfaces of horizontal openings A_h in roof and surfaces of floor A_f

$$bv=12.5(1+10\alpha_v-\alpha_v^2)=12.5(1+10\cdot 0{,}098-0{,}098^2)=24{,}63>10{,}0 \quad \textbf{(13)}$$
H the height of the fireplace H=2.7m,so, the value is:

$$w_f=(6.0/H)^{0.3}[0.62+90(0.4-0{,}098\alpha_v]^4/(1+24{,}63\cdot 0)]=1.739 \quad \textbf{(14)}$$
and finally, equivalent time of exposure to fire:

$$t_{e,d}=900\cdot 0{,}07\cdot 1{,}739=109{,}56 \text{ min} \quad \textbf{(15)}$$

3.2 Comparison of the rated and parametric temperature-time curve

As regards to fire parametres used in the Item 3.1, we compare the rated temperature-time curve:
$$\Theta g = 20+345 \log_{10}(8t+1) \quad \textbf{(16)}$$
The parametric temperature-time curve in the phase of heat is expressed by:

$$\Theta g = 1325(1-0.324e^{-0{,}2t^*} - 0{,}204\, e^{-1{,}7t^*} - 0.472\, e^{-0{,}19t^*}) \quad \textbf{(17)}$$

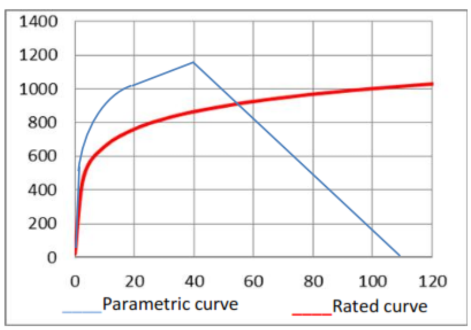

Fig.3. Rated and Parametric temperature time curves

4. Calculation of fire resistance

4.1 Tabulated data design

The simplest way to verify the fire resistance is the Tabulated data approach.. This method of verification of the fire resistance provides adequate security and does not require taking into account indirect loads or other similar effects.
This access enables to set the minimum dimensions of the cross section and minimum distance of the axis of the rebars to the border of the section , regards to the standard fire curve i.e. 30, 60, 90, 120, 180 or 240 minutes.

4.1.1 Beams

Based on the equivalent time of exposure to fire of 109.56 min, we apply the rated fire resistance R90 as shown in Table 5.6[3] based on which the minimum axial distance for the minimum width of beam of 250mm should be a = 25 mm, which in our case is fulfilled : beam 250 mm/ the axial distance 35 mm.
The axial distance a_{sd} in cases with one one layer reinforcement should be increased to 10mm, in our case the a_{sd} = 35mm. This condition is also fulfilled a_{sd} = 35mm,
Consequently, it is not necessary to change the maximum axial distance of beam in order to calculate fire resistance for R90

4.1.2 Columns

As regards to rated fire resistance R90, according to the table 3 for the columns exposed to fire in more than one side bmin=240mm, the minimum axial distance should be a=35 mm, which in our case is fulfilled Table 5.2a [3]-width of the beam 250 mm/ axial distance 36 mm.
As a result: it is not necessary to change the maximum axial distance in order to calculate fire resistance for R90

4.1.3 Temperature analysis

In annex A ,temperature profiles ,of (EN 1992-1-2) the isotherms are given for different cross-section and different specified times under standard heating conditions.In the annex B of the (EN 1992-1-2), we will use the profile with cross-sections 300x600 mm for the fire resistance R90 and R120 .

4.1.3.1 Cross-section resistance

Positive bending moment resistance of the beams may approximately obtained according to Annex E of EN 1992-1-2 by the expression:

$$M_{rd(\Theta)=}\Sigma k_{si}(\Theta)\cdot\ (f_{ski}\cdot A_{si}\cdot d_i) \qquad \textbf{(18)}$$

where :

$M_{rd(\Theta)}$ is the design resistance to positive bending of the element in the fire situation

$k_{si}(\Theta)$is the reduction factor of the characteristic yield strength of steel rebar i for the given temperature Θ

f_{ski} is the characteristic yield strength of the rebar i at normal temperature $f_{yk}(20^{O})C$

A_{si} is the nominal section of the rebar i

d_i is the effective static depth of rebar i

In the diagram from Figure 5.1 of [3], the reduction factor $k_{si}(\Theta)$ can be read, for the given temperature Θ for R90 and R120,than results $M_{rd(\Theta)}$. Compare: $M_{rd,(90min)=}$ 43,20 Knm with $M_{rd,0}$=62,27 Knm, results that $M_{rd,(90min)=}$69,4% of $M_{rd,0}$ (the cover for R90 was increased from 35 mm to 40 mm since for the case 35 mm for $M_{rd,(90min)}$=59% of R90 $M_{rd,0,}$ in an analogue manner $M_{rd,(120min)=}$78% of $M_{rd,0.}$

$$E_{fi,d,t} = E_{fi,d}= \eta_{fi} \qquad \textbf{(19)}$$

Calculation value of the effects of fire taking into account η_{fi} = 0,666 (or 0,64) is 66,6% of $M_{Ed,0}$ or (64% of $M_{Ed,0)}$ as a result the beams and reinforced bars meet the fire resistance.[4]

Conclusions

Upon verification of the resistance of the object B+G+11, in order to calculate fire resistance for R120 it is necessary to change the maximum axial distance of beam and columns. This is achieved by increasing the concrete cover to 40 mm from the axial distance of the reinforced steel bar to the end of the beam, which is:40+8+0.5x14=55 mm and by increasing the concrete cover for columns to 25 mm, the axis of the rebar Rϕ20mm to the border of the section should be: 25+8+0.5x20=43mm.
In general cases, the application of reinforced steel bars in more than a sequence allows for the possibility that the axial distances are not increased to 10 mm (although this reduces the cover and extends the necessary surface of the reinforced steel)
The bearing capacity of the building should be preserved in case of fire for a specific time.It could be of interest to get results established by more refined methods .

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