PRACTICAL WAY FOR DETERMINING THE FIRE RESISTANCE OF SQUARE REINFORCED CONCRETE SECTIONS WITH A SYMMETRICAL REINFORCEMENT, SUBJECTED TO BIAXIAL BENDING AND ALL-SIDED FIRE EXPOSURE

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Abstract. *Beams and plates in reinforced concrete structures, subjected to internal, edge and corner columns to biaxial bending. Based on the simplified calculation method, "Isotherm 500°C," in BDS EN 1992-1-2, are composed normalized interaction curves (nomograms) for determining the fire resistance of reinforced concrete square columns, subject of all-sided fire exposure. The nomograms are drawn up for columns, reinforced with four longitudinal bars at the corners of the section. Conclusions and recommendations are made for the practical application of the nomograms.*

Keywords*: fire resistance of reinforced concrete columns*

1. Introduction. Reinforced concrete columns are subjected to biaxial bending (compressive force applied to eccentricity on two principal axes of the section) at:

- transmission of unbalanced moments from beams and slabs along the main axis of the section;
- eccentrically loaded footing from bearing elements;
- asymmetrical change to the section;

- taking into account the imperfections (accidental eccentricity) for each direction of the cross-section;
- taking into account the effects of the second order for each direction of the section.

This paper examines square columns, subjected to biaxial bending and all-sided fire exposure, using the simplified calculation method, "Isotherm 500°C" [1]. This method is based on the hypothesis that the concrete at temperatures higher than 500°C is damaged and this zone from cross-section is neglected in the calculation of the load-bearing capacity. Concrete at temperatures below 500°C is assumed to retain its full strength, equal to the strength at 20°C. Calculations are conducted based on a reduced section with dimensions $h_{fi} = h - 2.a_z$, where a_z is the thickness of the damaged zone of the fire exposed sides. The damaged zone can be determined based on the temperature profiles presented in Annex A [1], based on other specialized literature, by solving the differential equation of the Fourier heat conduction equation in solids, or by using specialized software, which calculates the temperature distribution in concrete elements.

2. Calculation of square concrete sections with symmetrical reinforcement, subjected to biaxial bending and all-sided fire exposure. Physical processes and chemical reactions are changing the physical and mechanical properties in concrete and are reinforcing the steel exposed to elevated temperatures. The characteristic value of yield strength $f_{sy,\theta}$ for steel reinforcement decreases and the coefficient $k_s(\theta_i)$ for the reduced strength is reported in figure 4.2 in [1]. The design yield strength of the steel is determined by the formula $f_{sd,\theta} = f_{sy,\theta} / \gamma_{S,fi} = k_s(\theta_i).f_{yk} / \gamma_{S,fi}$, where f_{yk} is the characteristic value of the yield strength at a temperature of $20°C$ and $\gamma_{S,fi} = \gamma_{C,fi} = 1$ is the partial safety factor for the relevant material property (concrete and reinforcing steel) for fire exposure. The design compressive strength of concrete at elevated temperature is $f_{cd,fi} = \alpha_{cc}.f_{ck} / \gamma_{C,fi}$. The design cylindrical compressive strength of concrete at elevated temperature is $f_{cd,fi} = \alpha_{cc}.f_{ck} / \gamma_{C,fi}$. The coefficient $\alpha_{cc} = 0{,}85$ in the design of normal sections, bearing capacity of vertical or inclined elements, are implemented in a monolithic method [2]. Figure 1 shows the stages of heating a column, depending on the thickness of the damaged zone a_z and the distance, a. Three cases of the Isotherm 500°C position are defined:

a) $a_z < a$ – longitudinal reinforcement is inside the undamaged area of the section and the temperature is below 500°C;

b) $a_z = a$ – bearing reinforcement is located on the Isotherm 500°C and the thickness of the damaged zone a_z is equal to the distance, a;

c) $a_z > a$ – longitudinal reinforcement is outside the reduced cross-section and the temperature is above 500°C.

Figure 2 presents the decrease in bearing capacity of the section with development of the fire exposure. This is due to the increasing thickness of the damaged zone, , and the reduction of the yield strength of reinforcement steel.

Changing angle by degrees of 1^0 (fig.2, fig.3) and using equations for statics to axes passing through the center of reduced (no reduced) square cross-section, normalized interaction curves (nomograms) for different relations are composed.

The equations of statics are:

$$\sum M = 0 \rightarrow M_{fi,Ed} = A_{c,fi}.\eta f_{cd,fi}.d_{c,fi} + \sum_{i=1}^{n} A_{s,i,fi}.\sigma_{s(\theta),i}.d_{s,i,fi} \quad (1)$$

$$\sum H = 0 \rightarrow N_{fi,Ed} = A_{c,fi}.\eta f_{cd,fi} + \sum_{i=1}^{n} A_{s,i,fi}.\sigma_{s(\theta),i}, \quad (2)$$

where: $\sigma_{s(\theta),i}$ – are stresses in any longitudinal rebar with area $A_{s,i,fi}$ in the fire exposure;
$A_{c,i,fi}$ – is the area of the compression zone in the cross-section;

$d_{c,fi}$ – is the distance from the center of gravity of the compression zone to the axis, passing through the center of gravity of the section;

$d_{s,i,fi}$ – is the distance from the center of gravity of each longitudinal rebar to the axis, passing through the center of gravity of the section;

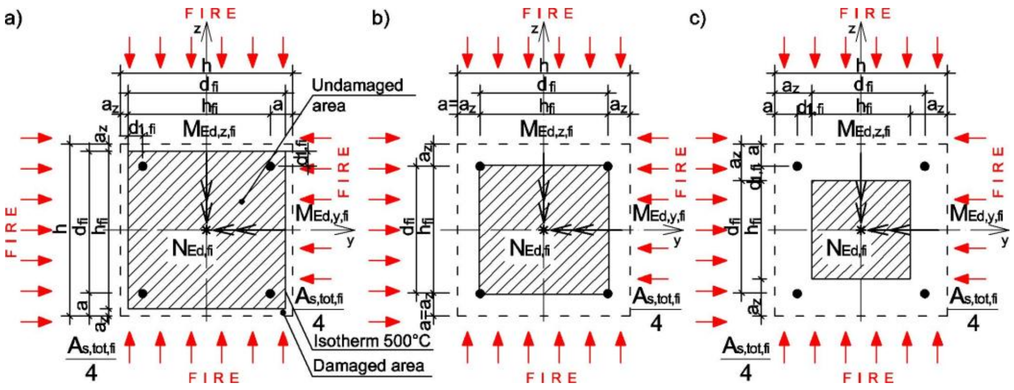

Fig. 1. Basic parameters and symbols in square column, subjected to biaxial bending and all-sided fire exposure, according to [1] at: a) $a_z < a$ *; b)* $a_z = a$ *; c)* $a_z > a$

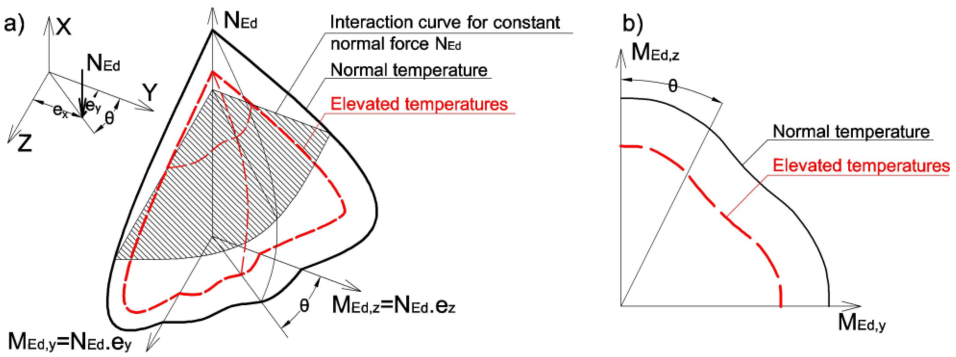

Fig. 2. Interaction curves of a square column, subjected to biaxial bending and all-sided fire exposure

The assumptions and validity of the proposed normalized interaction curves (nomograms) are:

- Hypothesis of Bernoulli - cross-sections, planar and perpendicular to the longitudinal axis of the element, remain planar and perpendicular after a deformation;
- shear deformations are very small and therefore are ignored;
- when, the longitudinal reinforcement is outside of the reduced cross-section and the temperature is above 500°C. It is assumed that the stability of the longitudinal reinforcement is provided by the steel stirrups and concrete, heated at a temperature higher than 500°C and located outside the reduced cross-section; Notwithstanding, that in the simplified calculation method, "Isotherm 500°C," is assumed that the concrete with temperatures higher than 500°C is damaged and does not contribute to the bearing capacity of the element, it is partially retained strength characteristics;
- columns with a square cross-section and four longitudinal rebar at the corners of the section are discussed;
- cylindrical compressive strength of concrete is;
- tensile strength of concrete is ignored;
- area of longitudinal reinforcement embedded outside of the area of splicing is where is the cross sectional area of the concrete;
- the method is valid for the reinforced concrete columns with a minimum width of the cross section, according to [1].

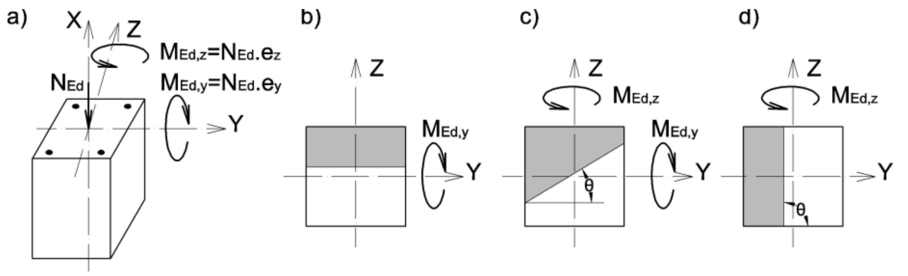

Fig. 3. Biaxial bending of a square column: a) three-dimensional view; b) bending about axis Y; c) bending about axes Y and Z; d) bending about axis Z [8]

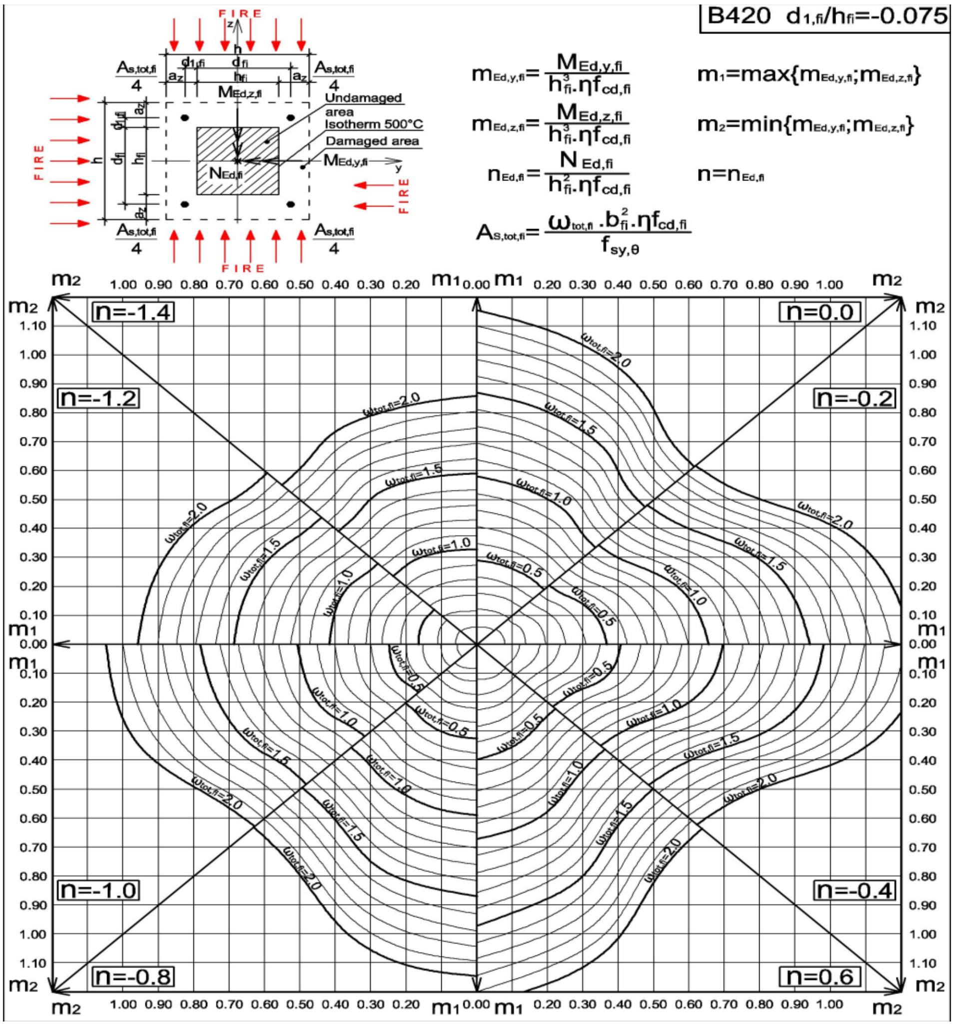

Fig. 4. Normalized interaction curve of a square reinforced concrete section with all-sided fire exposure, reinforced with four longitudinal rods class B420 at the corners and $d_{1,fi} / h_{fi} = -0{,}075$

Conclusions. After analyzing the established methodology and the attached normalized interaction curves, the following conclusions can be made:

a) the method is applicable to precast or monolithic square column sections, subjected to biaxial bending and four side fire exposure;

b) normalized interaction curves can be composed of different $d_{1,fi} / h_{fi}$ (0,000; -0,025; -0,050;…; -0,200) and different classes of reinforcing steel (B420, B500 and other);

c) for the center of gravity of the longitudinal reinforcement there are three defined cases of the Isotherm 500°C position:

- when $a_z < a$ is using normalized interaction curves for square columns, subjected to biaxial bending at normal temperature presented in [5], [6] and [7]. Parameters d_1/h, h, f_{yd}, f_{cd}, $m_{Ed,y}$, $m_{Ed,z}$ and n_{Ed} shall be replaced with $d_{1,fi}/h_{fi}$, h_{fi}, $f_{sy,\theta}$, $f_{cd,fi}$, $m_{Ed,y,fi}$, $m_{Ed,z,fi}$ and $n_{Ed,fi}$. Normalized interaction curves used in fire impact are similar to curves presented in [3] and [4];

- when $a_z = a$ and $a_z > a$ is using normalized curves for square columns, composed in this paper according to the proposed procedure;

d) proposed interaction curves can be applied to the determination of bearing capacity and the calculation of the reinforcement;

e) interaction curves can be used to design sections of columns, subjected to all-sides by standard fire exposure, according ISO834, or any other time heat regimes, which cause similar temperature fields in the fire exposed column;

f) reinforced concrete sections design, by the simplified calculation method "Isotherm 500°C", does not take into account the thermal expansion of material (concrete and reinforcing steel).

REFERENCES

1. БДС EN 1992-1-2:2005 и БДС EN 1992-1-2:2005/ NA - Еврокод 2: Проектиране на бетонни и стоманобетонни конструкции. Част 1-2: Общи правила. Проектиране на конструкции срещу въздействие от пожар.
2. Захариева-Георгиева Б. Проверка за огнеустойчивост на стоманобетонни колони чрез опростения изчислителен метод „Изотерма 500°С” на БДС EN 1992-1-2:2005, „сп. Строителство“, бр. 6, 2012 г.
3. Нешев Хр. Огнеустойчивост на правоъгълни стоманобетонни колони със симетрична армировка, подложени на огъващ момент и осова натискова сила при едностранно пожарно въздействие в равнината на огъващия момент, Първа научно- приложна конференция с международно участие. Стоманобетонни конструкции теория и практика– София, 2015г.;
4. Нешев Хр., Огнеустойчивост на правоъгълни стоманобетонни колони със симетрична армировка, подложени на огъващ момент и осова натискова сила при четиристранно пожарно въздействие, Първа научно- приложна конференция с международно участие. Стоманобетонни конструкции теория и практика– София, 2015г.;
5. Николов П. Стоманобетонни пътни мостове. Ръководство за проектиране, София, 2013г.
6. Русев К. Стоманобетон НПБСК-ЕС2, София, 2008г.
7. Русев К., В.Янчев ЕС2. Оразмеряване на стоманобетонни конструкции по нормални сечения, София, 2011г.
8. Charif A. Biaxial bending in columns
9. http://faculty.ksu.edu.sa/charif/Documents/Columns-Biaxial.pdf