BEARING CAPACITY FOR RECTANGULAR REINFORCED CONCRETE SECTIONS, SUBJECTED TO BIAXIAL BENDING AND ALL-SIDED FIRE EXPOSURE ACCORDING METHOD „ISOTHERM 500°C" IN BDS EN 1992-1-2

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Abstract. *Based on the presented simplified calculation method „Isotherm 500°C" in BDS EN 1992-1-2 is a composed procedure for determining the fire resistance of reinforced concrete rectangular sections of columns, subject of all-sided fire exposure. Conclusions and recommendations are made for practical application.*

Keywords: *fire resistance of reinforced concrete columns*

1. Introduction. Reinforced concrete columns are loaded to biaxial bending when unbalanced moments of floor structure are transmitted on the main axes, when eccentrically loads in two mutually perpendicular directions of beams are footing, when asymmetrical section is changing, and when is taking into account the effect of imperfections and second order effects for each direction of the element. The determination of stress distributions is considerably more complicated than uniaxial bending. In fire exposure on all sides the bearing capacity of section compounded determining. Usually, in practice, these sections civil engineer reinforcing with symmetrical rebar located around the perimeter of the section.

2. Calculation of rectangular concrete sections subjected to biaxial bending and all-sided fire exposure. Coefficient of thermal expansion of cement and aggregates are different and arise considerable stress, disruption of adhesion, and formation of cracks in the concrete structure. The temperature in element is changing from directly heated surface towards the center of the cross-section, which leads to irregularly deformation and occurrence of internal stresses. As a result of physical and chemical changes, chemical processes and nonuniformity thermal expansion, rapid heating and temperature rise in reinforced concrete element arise temperature stresses. They lead to partial or complete cracking of reinforced concrete columns. The strength properties of concrete from the exposed surface to the inside in the section decreased. Based on this phenomenon, there has been a developed method, "Isotherm 500°C" [1], which is based on the hypothesis that concrete with temperatures higher than 500°C is neglected in the calculation of load-bearing capacity, while concrete with temperatures below 500°C is assumed to retain its full strength. The thickness of the damaged concrete a_{500} is determined by the average depth of the 500°C Isotherm, using temperature profiles given in Annex A of [1] or other specialized literature.

In the methodology for calculation of rectangular cross-sections of concrete columns, subjected to biaxial bending and all-sided fire exposure, for determining characteristic value of yield strength $f_{sy,\theta}$ of steel reinforcement is used reduction factor $k_s(\theta_i)$, reported in figure 4.2 in [1]. The design value of yield strength of steel reinforcement under fire exposure is defined by the following formula:

$$f_{sd,\theta} = f_{sy,\theta} / \gamma_{S,fi} = k_s(\theta_i).f_{yk} / \gamma_{S,fi}, \qquad (1)$$

where f_{yk} represents the yield strength of reinforcing steel at 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. Design compressive strength of concrete at elevated temperature is $f_{cd,fi} = \alpha_{cc}.f_{ck} / \gamma_{C,fi}$. For calculation of bearing capacity in normal sections of vertical or inclined elements, made by monolithic construction method [2], is necessary to take into account the coefficient $\alpha_{cc} = 0,85$, given in Part 1-1 of Eurocode 2.

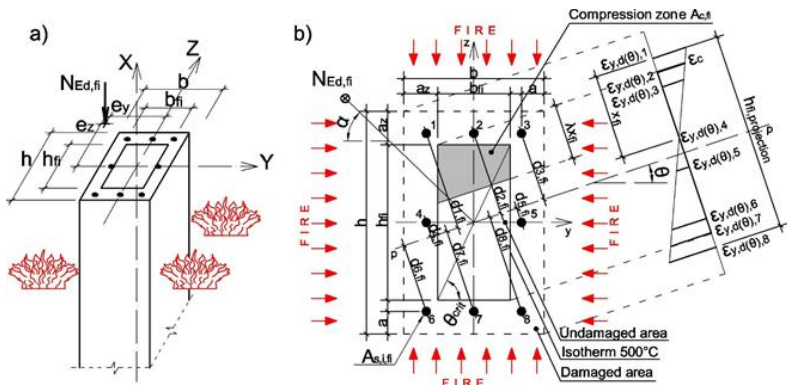

Fig. 1. Basic parameters and symbols in rectangular column subjected to biaxial bending and all-sided fire exposure, according to a [1]a) three-dimensional view; b) cross-section

To determine the fire resistance of column, subjected to biaxial bending, it is necessary to define angles α (the angle between the rights defined by the normal force $N_{Ed,fi}$ and the gravity center of the section and the axis y), θ_{crit} (the angle defined by connecting the two diagonal edges of the section and the axis y), and θ (the angle of inclination of the compression zone and the axis y) with the following formulas (fig.1):

$$\alpha = arctan\left(M_y / M_z\right); \qquad (2)$$

$$\theta_{crit} = arctan\left(h_t / b_t\right); \qquad (3)$$

$$\theta = 90 - y - c - z/\sqrt{2}; \qquad (4)$$

$$y = c/2 + \sqrt{c^2/4 - x^2 + cx};. \qquad (5)$$

$$c = 127/\left(h_t/b_t - 1\right) = 127b_t/\left(h_t - b_t\right)\left(ако\ \ h_t/b_t = 1; \theta = \alpha\right); \qquad (6)$$

$$x = \alpha + c - z/\sqrt{2}; \qquad (7)$$

$$z = -13.\left(h_t/b_t - 1\right)^2 + 39,4.\left(h_t/b_t - 1\right) + 63,6 \qquad (8)$$

Equations (2.4) to (2.8) define the angle of inclination of the compression zone and the axis y, according to the procedure presented in [5]. In the formulas, the size of the reduced cross-section determines - $h_t = h - 2.a_z$ and $b_t = b - 2.a_z$. Bending moments of the main axes of section $M_{y,fi,Ed} = N_{Ed,fi}.e_z$ and $M_{z,fi,Ed} = N_{Ed,fi}.e_y$ are determined. The influence of longitudinalreinforcement is not taking into account the value of angle θ.

Based on the calculation for angle θ and the amending by steps of compression zone is determined:

- the geometric path distances $d_{i,fi}$ from axis p (the axis is defined by the angle passing through the center of gravity of the cross section of the column) to the center of gravity of the longitudinal reinforcement;
- the strain at yield stress of steel reinforcement $\varepsilon_{y,d(\theta)}$;
- the area of the compression zone $A_{c,fi}$;
- areas $A_{c,fi,j}$;
- distances $d_{c,j,fi}$ from axes p to the center of gravity of the areas $A_{c\ fi\ j}$. In figure 2 shows the division of parts for the compression zone of section at $\theta \le \theta_{crit}$, and in figure 3 – at $\theta > \theta_{crit}$. The compression zone changes from a triangular to a trapezoidal shape and fully compresses the cross section.

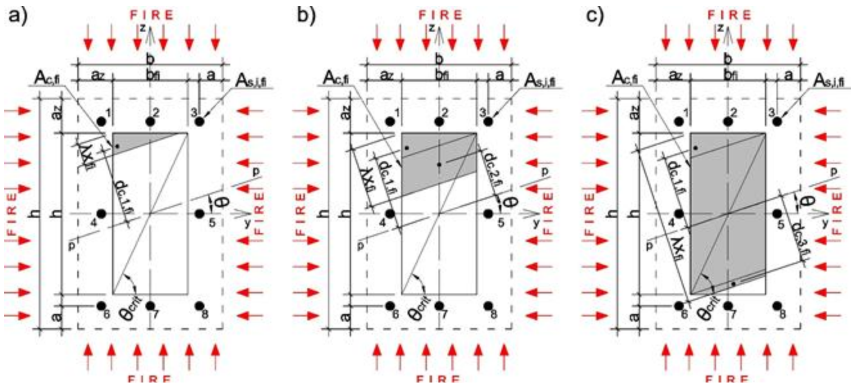

Fig. 2. Determining the area of the compression zone and the distance $d_{c,j,fi}$ *at* $\theta \le \theta_{crit}$

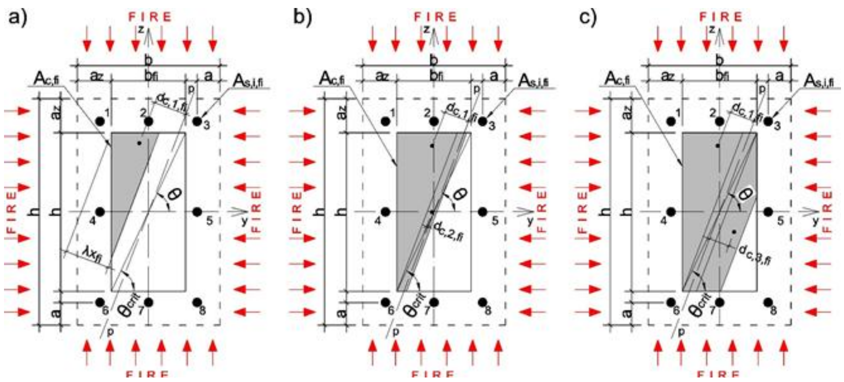

Fig. 3. Determining the area of the compression zone and the distance $d_{c,j,fi}$ *at* $\theta > \theta_{crit}$

The equations for statics to axes p, passing through the center of gravity of the section are:

$$\sum M = 0 \rightarrow M_{\theta,fi,Rd} = \sum_{j=1}^{m} A_{c,fi,j}.\eta f_{cd,fi}.d_{c,j,fi} + \sum_{i=1}^{n} A_{s,i,fi}.\sigma_{yd(\theta),i}.d_{i,fi}; \quad (9)$$

$$\sum H = 0 \rightarrow N_{fi,Rd} = \sum_{j=1}^{m} A_{c,fi,j}.\eta f_{cd,fi} + \sum_{i=1}^{n} A_{s,i,fi}.\sigma_{yd(\theta),i} \quad (10)$$

Based on equations (2.9) and (2.10), an interaction curve of column is drawn for the relevant angle θ, which is determined by the size of the reduced cross-section and the bending moments. The calculation for the bending moment is conducted as follows:

$$M_{\alpha,fi,Ed} = \sqrt{M_{y,fi,Ed}^{2} + M_{z,fi,Ed}^{2}} \tag{11}$$

The internal forces $N_{fi,Ed}$ and $M_{\alpha,fi,Ed}$ with bearing capacity of the section are then compared:

$$N_{fi,Ed} \le N_{fi,Rd}; \tag{12}$$

$$M_{\alpha,fi,Ed} \le M_{\theta,fi,Rd} \tag{13}$$

The assumptions and validity of the proposed procedure for the calculation are:

- cross section remains plane after bending and normal to the centroidal axis (hypothesis of Bernoulli);
- shear deformations are very small and therefore are ignored;
- concerned columns have a rectangular cross section;
- cylindrical compressive strength of concrete is $f_{c,k} \le 50MPa$;
- tensile strength of concrete is ignored;
- area of longitudinal reinforcement embedded outside of the area of splicing is $A_s \le 0,04A_c$

where A_c is the area of the concrete section;

- the method is valid for the reinforced concrete columns with a minimum width of the cross section $b_{\min}$, according to [1].

Figure 4 shows the block-scheme for the constructed procedure.

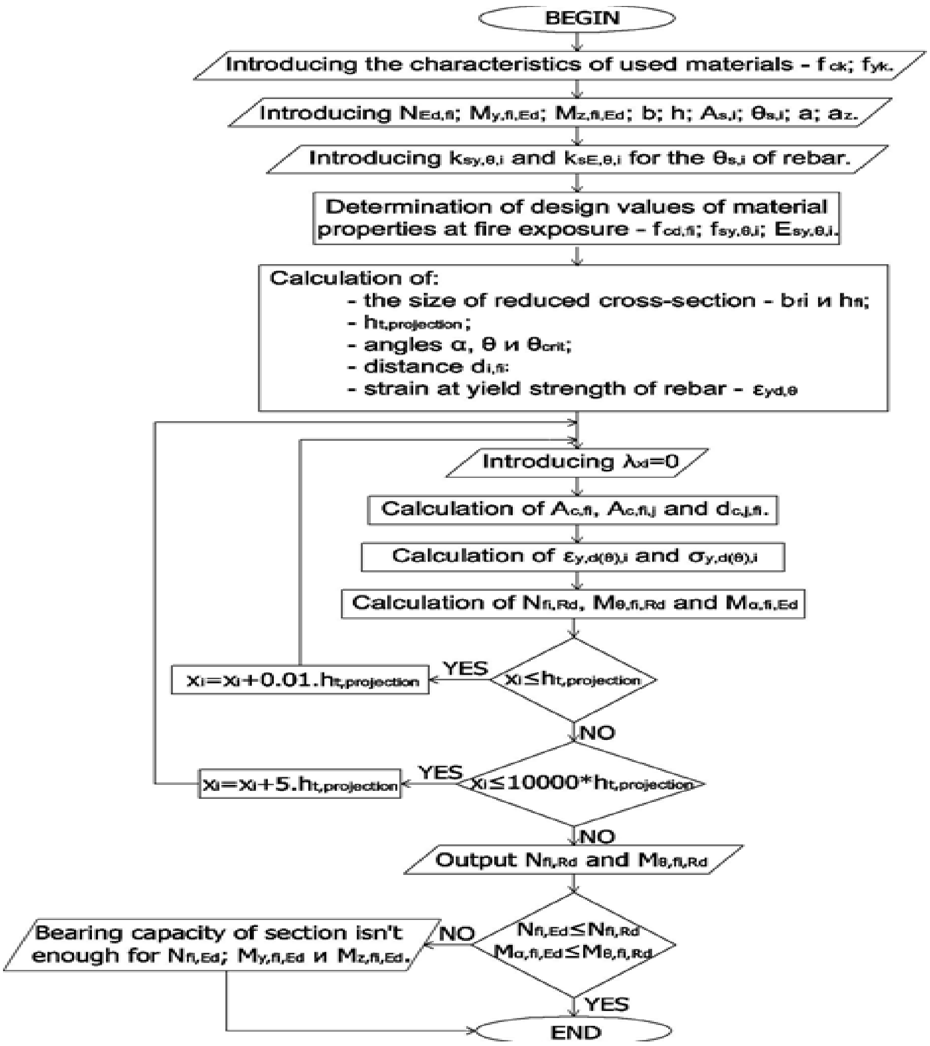

Fig. 4. Block-scheme

3. Numerical example. Check the fire resistance of the rectangular reinforced concrete cross-section with dimensions of 500/300mm, reinforced with longitudinal reinforcement $8N16$, loaded with compressive force and bending moments, and standard fire exposure. The design values are: $N_{fi,Ed} = 500kN$, $M_{y,fi,Ed} = 60kNm$ and $M_{z,fi,Ed} = 40kNm$ (fig.5). The compressive cylin-der strength of concrete C25/30 is $f_{cd} = 25MPa$ and the hot rolled reinforcing steel is class B500. The required fire resistance of the column is 90 minutes.

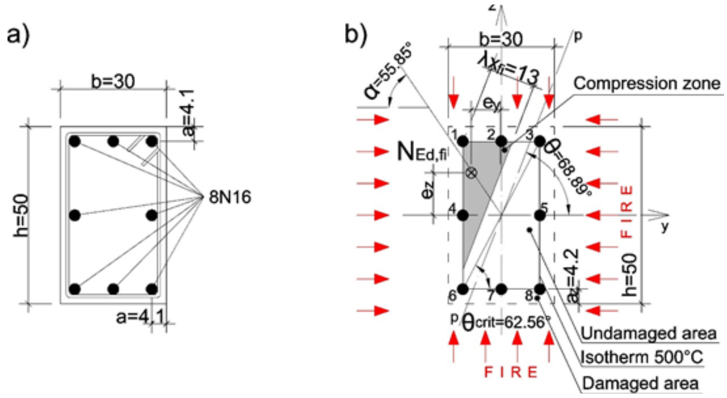

Fig. 5. Cross-section: a) at normal temperature; b) at standard fire exposure for a duration of 90 min

Annex A of [1] reports the thickness of the damaged concrete $a_{500} = a_z = 4,2cm$, the temperature of the corner rebar, which is $\theta = 630°C$, and the temperature of the internal reinforcement, which is $\theta = 425°C$. Angles α, θ_{crit} and θ are calculated based on the created program. The interaction curve for angle $\theta = 68,89°$ is built. Figure 6 shows the specified loads and fire resistance of the column for a standard fire exposure of 90min.

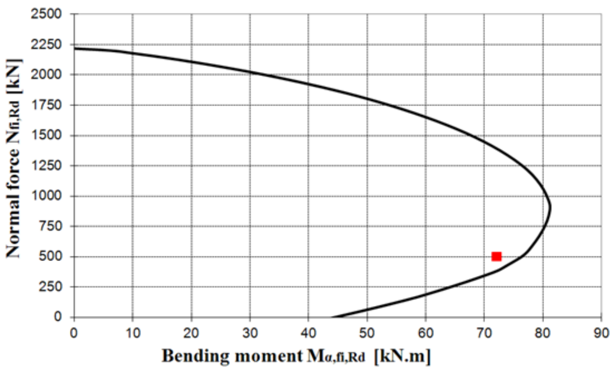

Fig. 6. Interaction curve of section of angle $\theta = 68,89°$

Conclusions. After analyzing the established methodology and calculation procedure, we came up with the following conclusions:

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

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

c) the calculations are based on the "Isotherm 500°C" method, where stress-strain diagrams of concrete and reinforcement steel are bilinear and concrete at a temperature below 500°C is assumed to retain its full strength. A more accurate method for calculating the fire resistance utilizes nonlinear stress-strain material curves (concrete and reinforcing steel) at elevated temperatures, as well as the exact temperature of the concrete at each point of section [3], [4]. However, this method is more complicated for civil engineers to implement in practice;

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

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