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Structural Mechanics

General and Particular in Checking up the Building Structures to Fire Action According to Eurocodes

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Abstract
In the present paper, a comparative analysis of parts1.2 from Eurocodes 2, 3 and 5 is performed.. The common and the specific features are pointed out, in order to have a unitary understanding of fire design problems for the main types of building structures.

The work defines first of all the fire action, identifying models which may belong to one of the following categories:

- *reference scenario or design fire for natural/parametric fires;*
- *reference scenario or design fire for conventional/nominal fires,*

and evaluates the states of loading for the elements, subassemblies and structures

The specific requirements referring to strength, time and temperature are approached. Finally, the paper shows the methods used in the assessment of the internal forces produced by the design loads and of the carrying capacity, both in case of fire.

KEYWORD: fire security, fire risk, design fire, active protection, passive protection, operative protection

1. INTRODUCTION

According to *General Measures for the Fight against Fires* (No.163/28.02.2007), as concerns the design and carrying out of constructions and equipments (chapter III), it is stated that in case of a fire they must ensure along their whole life:

- the stability of structural elements for a certain period of time;
- the limitation of fire and smoke propagation inside the construction;
- the limitation of fire propagation to the neighbors;
- the possibility of a safe evacuation for the users or the possibility of being saved by using other means;
- the security of the intervention forces.

The fire security has as objective to reduce the fire risk by:

- measures of *passive protection,* which must be adopted in the building design and during its construction and they must be maintained along the whole building life;

- measures of *active protection*, by providing appropriate equipments and technical means for fighting against fires;
- measures of *operative protection*, by organizing activities of fighting against fires and ensuring the fire men intervention.

The essential requirement *fire security* should be assured by specific measures and rules as concerns:

- the location, design, construction and service of buildings, equipments etc;
- the performance of structures, equipments, as well as of construction products (materials, elements, subassemblies).

The assessment of structures strength and stability in case of fire action is based on experiments which use the *reference scenario*, according to European codes, or on design methods which use *design fires* according to Eurocodes (part 1.2).

According to Order no. 163/28.02/2007, chapter III, section 2, in case of a fire, the structure of a building must preserve its stability in order to:

- assure the users security for a certain period of time, as well as for the intervention forces;
- avoid the building collapse;
- assure the accomplishment of the construction product specific functions for a certain period of time.

Eurocode 1 contains a part (1.2), which refers to the *fire exposure of structures*. The problem is approached in terms of structural design which must assure an adequate stability of the structural members and the limitation of fire evolution (in fact measures of passive protection).

The methods for the evaluation of thermal and mechanical effects of fire action are mentioned, this action being considered as an accidental one.

The general procedure for designing the structures to fire action presumes the following stages:

- selection of *design fire scenario*;
- evaluation of *design fires*;
- *heat transfer calculus* inside the structural elements;
- *deformability calculus* of the exposed structural elements;

2. FIRE MODELS

The fire is a combustion which develops without any control in time and space.

It depends on a lot of factors: the shape and sizes of the room, the thermal load, the openings, the nature and position of combustible materials, the location of fire, the location of the room in the building etc.

In case of a fire produced inside a room, the following stages could be defined:

- the fire breaking out ;
- the fire development, in three different manner: the *flash-over* phenomenon (when the fire extends over the whole surface of the combustible materials in the room because it is enough oxygen in the room), fire regression and spontaneous extinction or, the occurrence of *back-draft phenomenon* (when the oxygen decreases in the room);
- fire generalization, when the combustion extends in the whole room, the temperature has a maximum uniform value and the heat transfer by radiation becomes preponderant;
- fire regression, when the temperature decreases because there is no more combustible.

The action of fire is of thermal nature, mechanical nature or their combination.

The *mechanical action* could consist in loads, imposed deformations, temperature changes. The *thermal action* may be the consequence of radiation, convection and conduction phenomena.

The level of thermal action related to time defines the stage of the fire development and could be simulated in order to asses the performance of a construction product.

There are several *fire models,* depending on the desired objective in the fire performance assessment.

Case of Reaction to Fire Action Performance

In this case, the fire model, called **reference scenario**, considers a fire which breaks out in a room, develops and could attain the flash-over point. It follows three stages in fire development:

- initialization (simulated by lightening up a product with a small flame, on a limited surface of the product);
- development (simulated with a product burning in a corner of the room, generating a heat flux towards the neighbor surfaces – method SBI);
- post-flash-over (simulated by all combustible products burning, that is the generalized burning).

Case of Resistance to Fire Action Performance

In this case, the fire model called *reference scenario* or *design fire*, is based on a curve temperature – time, which defines the evolution of gasses temperature in the neighborhood of structural element surface.

In order to define a *natural/parametric fire,* in the evaluation of its thermal action, the following elements should be considered: the thermal load (type, quantity, combustion velocity), the shape and the dimensions of the elements which separates the fire compartment, the thermal and mechanical properties of non-structural elements, the fire extinction equipments, the action of fire men team.

Eurocode 1: (*Basis of Design and Actions on Structures*), Part 1.2. *(Action on Structures Exposed to Fire*) states relation (1) for a natural/parametric fire:

$$T = 1325(1 - 0.324e^{-0.2t^*} - 0.204e^{1.7t^*} - 0.472e^{-19t^*} \quad (1)$$

where T is the temperature of gasses, in ^{0}C and t^* is the time depending on the ventilation factor and on the thermal inertia of the surrounding walls.

The requirement *fire security* imposes the limitation of the fire propagation and the stability of the building for a certain period of time. This requirement implies the resistance to fire action of structural and/or non-structural elements.

The model (conventional) for the thermal action, which corresponds to a generalized fire, is that one given by the *standard curve temperature-time* (ISO 834):

$$T = T_0 + 345\log_{10}(8t + 1) \quad (2)$$

where:

T is the gasses temperature, in ^{0}C;

T_0 is the initial temperature, generally 20^0;

t is the duration of the thermal exposure, in minutes.

This model of thermal action is used in the assessment of performances for the products exposed to fire in full development.

The thermal action model (conventional), in case of a more severe fire (with a higher rate of temperature increasing than that given by the standard curve), may be given by the hydrocarbons harmonized curve:

$$T = 1080(1 - 0.325^{0.167t} - 0.675^{-2.5t} + 20) \quad (3)$$

where t is the time given in minutes.

The thermal action model in case of a smoldering fire (with a lower rate of temperature increasing than that given by the standard curve) is given by the smoldering burning curve:

$$T = 154t^{0.25} + 20 \quad (4)$$

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For special constructions (like traffic tunnels, nuclear plants etc.), extreme fire scenarios are adopted and the conventional model of the thermal action is defined by curves that describe severe situations.

The thermal action of fire is expressed by the *total heat flux,* h_{net} (convective, $h_{net,c}$ and radiant $h_{net,r}$) applied to the element, substructure or structure (rel.5). The two safety coefficients, $\gamma_{n,c}$ and $\gamma_{n,r}$ have different values for each country.

$$\dot{h}_{net} = \gamma_{n,c} \cdot \dot{h}_{net,c} + \gamma_{n,r} \dot{h}_{net,r} \tag{5}$$

The fire action upon building structures is considered as an accidental one and belongs to the extraordinary actions. It is never considered with another accidental action like the earthquake.

The loads during the fire are those considered for the normal temperature. The diminishing of loads produced by fire is not allowed. The snow melting is analyzed from case to case and the loads resulted from the technological procedures are not considered in combination with fire action. Sometimes, additional impact loads are taken into account.

The advanced design methods in case of fire action must offer a realistic analysis of the element, substructure or structure and propose specific design models for:

- the evaluation of temperature distribution in the structural elements (thermal response);
- the structural deformability (static response).

3. CHECKING THE BUILDING STRUCTURES TO FIRE ACTION

3.1. Actions and Combinations of Actions

The code *CR 0-2005 – Design Code. The Basis of Building Structures Design* (equivalent to Eurocode 0) is a result of the work of harmonizing the technical Romanian and European legislation.

The building structures design is performed by using *the method of partially safety coefficients,* which consists in checking all the design situations, so that no limit state to be exceeded when the design loads or effects and the design strengths are used.

In case of checking up an element, a substructure or a structure at the ultimate limit state, the design effort in fire conditions is determined based on the combination of loads given by the following relation:

$$\Sigma\gamma_{GA} G_{kj} + \psi_{1,1} Q_{k,1} + \Sigma\psi_{2,i} Q_{k,i} + \Sigma A_d(t) \tag{6}$$

where:

$G_{k,j}$ is the current permanent load, j;

γ_{GA} (=1.0) is the partial safety coefficient for permanent loads at the ultimate limit state, in fire conditions;

$Q_{k,1}$ is the variable dominant load;

$\psi_{1,1}$ is the combination coefficient for the variable dominant load, (see Table 1);

$Q_{k,i}$ is the current variable load, i;

$\psi_{2,i}$ is the combination coefficient for the current variable load, (see Table 1);

$A_d(t)$ refers to the accidental fire action.

Table.1 Combination coefficients for the ultimate limit state in fire conditions

Actions	*Combination coefficients*	
Imposed loads in buildings	$\psi_{1(,1)}$	$\Psi_{2(,i)}$
Category A, dwelling	0.5	0.3
Category B, dwelling	0.5	0.3
Category C, dwelling	0.7	0.6
Category D, dwelling	0.7	0.6
Category E, dwelling	0.9	0.8
Snow	0.2	0
Wind	0.5	0

3.2. CHECKING UP METHODS

There are two types of analytical methods for checking up a structure submitted to the fire action: general methods and particular methods (specific to each type of structure).

Besides analytical methods, there are also used experimental test results.

General Checking up Methods

The strength requirement expressed according to this method for a time, t, of exposure to fire is:

$$E_{fi,d} \le R_{fi,d,t} \quad (7)$$

where:

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- $E_{fi,d}$ is the effort produced by the loads resulted according to relation (6) (including the efforts given by the axial temperature change and by the temperature gradient on the element cross-section);
- $R_{fi,d,t}$ is the carrying capacity of the cross-section at the ultimate limit state, in fire conditions, at time t.

For checking up a structure to fire action is enough to check up the structural elements, if the model is given by the standard curve (2).

In case of checking up the structural element or the substructure, there is an alternative simplified method, for the evaluation of effort $E_{fi,d}$, which is called the *method of the reduction coefficient.*

This method, which is applied to all kinds of structures (made of concrete, steel, wood etc.) offers the possibility of computing $E_{fi,d}$, by performing an analysis at moment $t=0$ and for normal temperature (section 4 from EN 1991-1-2), according to the following

$$E_{fi,d} = \eta_{fi} \cdot E_d \tag{8}$$

where η_{fi} is the reduction coefficient for the design loads in case of fire. It is determined with the formula:

$$\eta_{fi} = \frac{(G_k + \psi_{fi} Q_{k,1})}{(\gamma_G G_K + \gamma_{Q,1} Q_{k,1})} \tag{9}$$

or has the minimum value given by relations:

$$\eta_{fi} = \frac{(G_k + \psi_{fi} Q_{k,1})}{(\gamma_G G_K + \psi_{0,1} \gamma_{Q,1} Q_{k,1})} \tag{9.1}$$

$$\eta_{fi} = \frac{(G_k + \psi_{fi} Q_{k,1})}{(\varsigma \gamma_G G_K + \gamma_{Q,1} Q_{k,1})} \tag{9.2}$$

where:

- G_k is the characteristic value of the permanent loads;
- $Q_{k,1}$ is the characteristic value of the principal variable load;
- ψ_{fi} is the coefficient of variable loads in the fire combination, given by $\psi_{1,1}$, or by $\psi_{2,1}$ (EN 1991-1-2: 2002);
- γ_G is the partial safety coefficient for the permanent loads ($\gamma_G=1.35$); $\gamma_{Q,1}$ is partial safety coefficient for the variable load 1 ($\gamma_{Q1}=1.50$);
- ζ is the reduction coefficient for the unfavorable permanent load, G.

For the common concrete buildings $\eta_{fi}=0.70$, for steel structures $\eta_{fi}=0.65$ (for category A-D) or $\eta_{fi}=0.70$ (for category E). In case of wood structures $\eta_{fi}=0.60$ (for caregory A-D) or $\eta_{fi}=0.70$ (for category E).

In the effort $E_{fi,d}$ evaluation, there are taken into account: the collapse manner, the material properties changes caused by temperature, the support conditions which should be valid along the whole exposure to fire. Only for substructures and structures, the indirect thermal effects, derived from the thermal gradient on the cross-section of the element, are also considered.

Particular Checking up Methods

The checking up requirements for structural elements may be expressed in terms of time or temperature, too.

In terms of *time*, the requirement has the form:

$$t_{fi,d} \le t_{req} \tag{10}$$

where: $t_{fi,d}$ is the design time for exposure to fire and t_{req} is the required time for maintaining the structural element functions in case of a fire.

The structural elements made of concrete are generally checked up by using this method.

Another particular method refers to *temperatures.* According to this method:

$$\theta_d \le \theta_{d,cr} \tag{11}$$

where θ_d is the design temperature which may be attained during the exposure to fire and $\theta_{d,cr}$ is the critical design temperature characteristic to the material, the element is made of.

4. CONCLUSIONS

The conclusions of the present paper can be shortly expressed in the following scheme, which contains the main aspects of the checking up procedures in case of structures subjected to fires.

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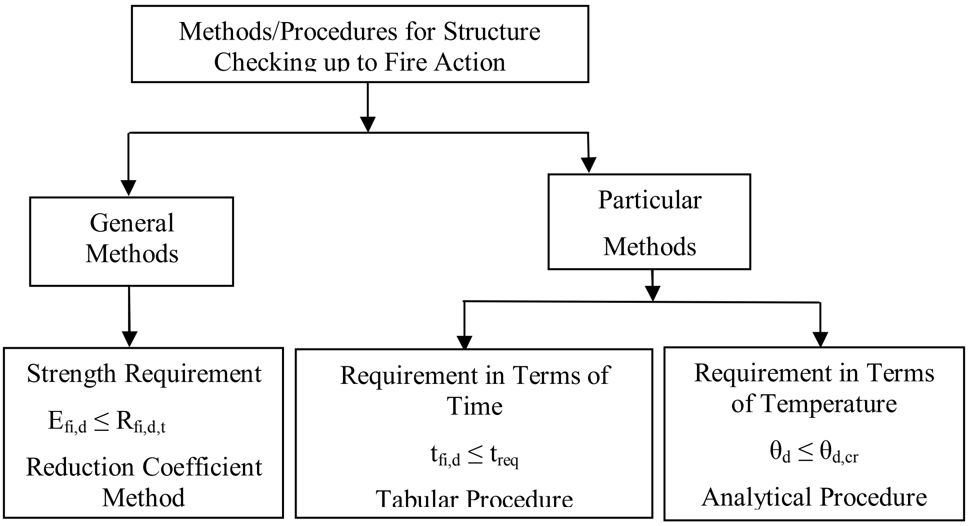

Figure1

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