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# EVALUATION OF STEEL ELEMENT'S STRENGTH AT HIGH TEMPERATURE (FIRE)

BY

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In the first part of the paper there shall be considerations on the hypothesis and possibilities of assessing the fire resistance of the steel structural elements. After the critical presentation and analysis of the breaking criteria used regarding structures' calculations at high temperatures, the way of determining the fire resistance of a metal beam stressed at pure bending is presented.

## 1. Introduction

The structures' protection against action of high temperatures (fires) depends firstly on the good design of the structure as a whole. The proper structural devices and an improper layout of the structural elements and materials allow for the limitation of a hazardous fire occurrence. Same attention should be paid to the assessment of the fire resistance of the elements (at least of the most important) and of the structure as a whole.

With regard to the structural assessment as a whole, two different ways could be used. One method consists in conducting experimental studies in ovens where the conditions of a fire development be simulated. Another technique consists of using the simulation of theoretical methods which allow the solving of the issue numerically.

Both methods have benefits and disadvantages. For the experimental methods, the difficulties of simulating, in a satisfactory manner, the conditions in which a fire develops need to be highlighted. The theoretical methods present a certain number of benefits in relation with the experimental ones, nevertheless their perfecting is rather difficult and it requires a long time.

The theoretical methods allow the investigation by calculation of the important structures for which practically it is possible to conduct experiments in the ovens. They are less expensive, especially if the calculation infrastructure is perfected.

We should note the fact that the extrapolation of some theoretical results needs to be carefully performed. Most of the time, under these circumstances, the experimental support is indispensable for the hypotheses and the adopted theoretical schemas control.

## 2. Critical Temperature, Breaking Criteria

Within the general framework of the hypotheses admitted in the calculation at high temperatures (fire) we propose the following conditions: *the critical temperature of a resistance element is the temperature, supposed uniform, upon formation of the breaking mechanism.*

*As a result, the fire resistance, $R_f$, is the time necessary to reach the critical temperature* [1].

In the field of metal structures fire calculation, there are three breaking criteria frequently used:

a) The Ryan and Robertson criterion, which defines a limit deformation speed by the relation

$$\frac{\mathrm{d}f}{\mathrm{d}t} = \frac{l^2}{9,000h}, \tag{1}$$

where: $f$ is the arrow, $h$ – the beam height, $l$ – the beam opening.

b) The criterion defined by the limit arrow (criterion adopted by the French and Belgian norms)

$$f = \frac{l}{30}. \tag{2}$$

c) The criterion of the deformation infinite speed

$$\frac{\mathrm{d}f}{\mathrm{d}t} \to \infty. \tag{3}$$

The first two criteria practically lead to the same results in case of the metal structures.

This conclusion is not valid in case of materials with low thermal conductivity such as concrete, for which the section thermal gradient can determine by itself the reaching of the limit arrow criterion, without compromising stability [2].

## 3. Assessment of the Fire Resistance of a Steel Beam Stressed at Pure Bending

A steel beam, subject to pure bending, is considered, in which, the extreme stresses are at the limit of the elastic range. In order to examine the evolution of the section stresses, the steel properties at high temperatures need to be known. From the hypotheses admitted in the fire calculation, we retain for this study the hypothesis concerning the fact that stresses deformations chart remains elastic- perfectly elastic to any temperature (Fig. 1).

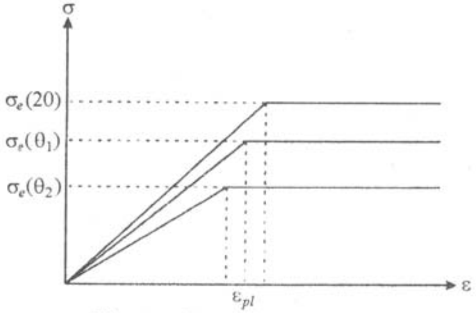

Fig. 1.- Dependence $\sigma$ *vs.* $\varepsilon$.

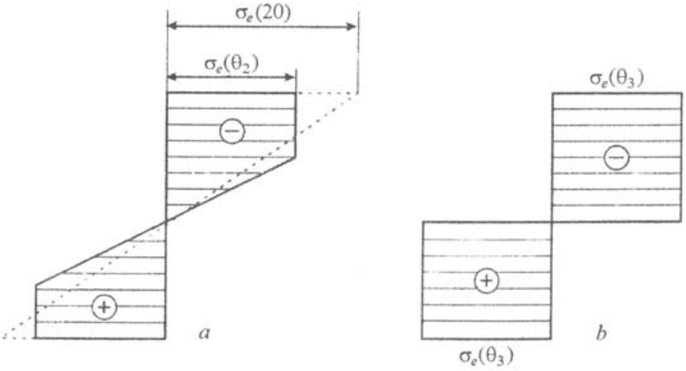

Fig. 2.- Plasticization of the cross section.

In this case, the elastic limit, $\sigma_e(\theta)$, decreases in accordance with the laws indicated in Fig. 3. The stress phenomenon can be shortly synthesized as follows: at ambient temperature, the distribution of the section normal stresses is linear at the limit of the elastic range; in the extreme fibers the stresses have the value $\sigma_e(20)$ (Fig. 2 *a*). From this moment, the section plasticization is progressively extending from the section ends, the same as in the case of the element stress by the progressive increase of outer actions.

In accordance with Fig. 1 *b*, at a temperature $\theta_2 > \theta_1 > 20°\text{C}$, $\sigma_e(\theta_2) < \sigma_e(20)$, the redistribution of the stresses in the section occurs and their section chart is in accordance with Fig. 2 *b*.

We suppose that the plasticization of the entire section (Fig. 2 *b*) occurs at temperature $\theta_3 = \theta_{\text{cr}}$, the bending moment reaches the value of the plastic moment, $M_p$, which is determined with the relation

$$M_p = \sigma_e(\theta_{\text{cr}})W_p$$

and consequently

$$\sigma_e(\theta_{\text{cr}}) = \frac{M_p}{W_p}, \tag{4}$$

where $W_p = 2S_0$ is the moment of the section plastic moment

We adopt for the ratio $r(\theta) = \sigma_e(\theta)/\sigma_e(20)$ the relation

$$r(\theta) = 1 - a\,\theta^2, \tag{5}$$

according to the elasticity limit, $\sigma_e(\theta)$, corresponding to a remaining deformation of 0.5% (Fig. 3). In these conditions

$$r(\theta_{\text{cr}}) = \frac{M(20)}{M_p(\theta_{\text{cr}})} = 1 - a\,\theta_{\text{cr}}^2, \tag{6}$$

and having in view (5) and (6) it results

$$\theta_{\text{cr}} = \sqrt{\frac{1}{a}\left[1 - \frac{M(20)}{M_p(\theta_{\text{cr}})}\right]}; \tag{7}$$

the fire resistance is the time to reach the temperature $\theta_{\text{cr}}$.

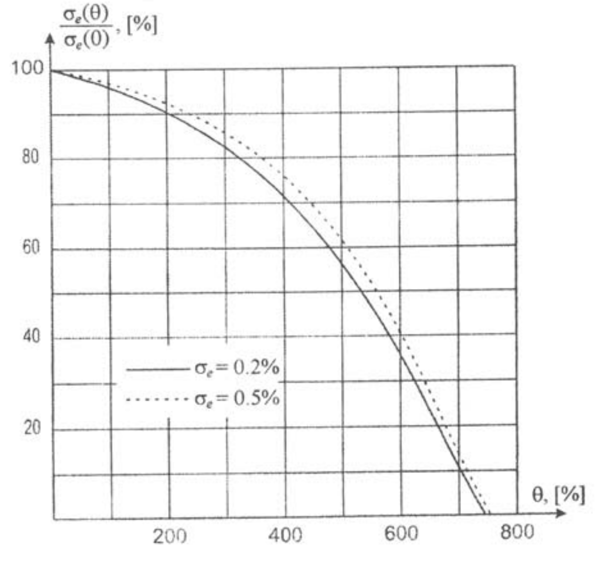

Fig. 3. Variation of the elasticity limit with the temperature.

## 4. Observations. Conclusions

The theoretical pattern presented in the previous sections is based on the hypothesis that the temperature is uniformly distributed in the profile section. In case of real structures this condition is rarely reached. The pillars, in general, are located at least partially inside the walls, therefore their surface is exposed only partially to fire. The same situation can be encountered in case of floor-integrated beams.

In order to perform a calculation based on this hypothesis, for real structures, the same can be accepted only as an approximate solution.

The existence of colder areas adjacent to the walls, floors, etc, brings relevant perturbations in the heat exchange.

In order to consider these phenomena, experimental results must be used or, in the theoretical calculation must be used more refined calculation hypotheses and more rigorous calculation patterns.

These options very much complicate both the calculation of the section and the structure analysis. In the first case, the plastic moment cannot be found as a simple relation and in the second one, the breaking mechanism cannot be directly determined.

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## EVALUAREA REZISTENŢEI ELEMENTELOR STRUCTURALE DIN OŢEL LA TEMPERATURI ÎNALTE (FOC)

(Rezumat)

În prima parte a lucrării se fac aprecieri asupra ipotezelor şi posibilităţilor de evaluare a rezistenţei la foc a elementelor de rezistenţă din oţel. După prezentarea şi analiza critică a criteriilor de cedare utilizate în calculul structurilor la temperaturi înalte se indică modul de determinare al rezistenţei la foc pentru o grindă metalică solicitată la încovoiere pură.