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Autor: Schleich, Jean-Baptiste

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Eurocode 1 / Part 2.2
Actions on structures exposed to fire

Jean-Baptiste SCHLEICH
Ingénieur Principal
ProfilARBED Recherches
Esch/Alzette
LUXEMBOURG

Jean-Baptiste Schleich, born in 1942 got his civil engineering degree 1967 at the University of Liège. Responsible since 1984 for research in steel construction at ProfilARBED, he was President of ECCS in 1985 and 1994. He is the representative of Luxembourg in CEN/TC250 and was Convenor of Part 1.2 of Eurocode 4.

Summary

This Part 2.2 of Eurocode 1 is concerned with actions on structures exposed to fire. It is intended for use in conjunction with the fire design Parts of ENV 1992 to 1996 and ENV 1999 which give rules for designing structures for fire resistance. Thermal actions given in the main text of ENV 1991-2-2 are mainly confined to nominal thermal actions. Some data and models for physically based and more realistic thermal actions are given in informative annexes which may be improved by ongoing research. Mechanical actions shall be combined in accordance with ENV 1991-1 "Basis of design" using the accidental combination.

1. Introduction

The European Commission issued on 21 December 1988 [1] a directive concerning the products used in the construction of buildings and civil engineering works (Construction Product Directive "CPD").
The term "construction product" refers to products produced for incorporation, in a permanent manner, in the works and placed as such on the market. It includes materials, elements, and components of prefabricated systems or installations which enable the works to meet the essential requirements.

The following essential requirements have to be fulfilled:

1. Mechanical resistance and stability,
2. Safety in case of fire,
3. Hygiene, health and environment,
4. Safety in use,
5. Protection against noise,
6. Energy economy and heat retention.

Concerning "safety in case of fire", the Directive states:

"the construction works must be designed and built in such a way that in the event of an outbreak of fire:
* the load bearing capacity of the construction can be assumed for a specific period of time,
* the generation and spread of fire and smoke within the works are limited,
* the spread of fire to neighbouring construction works is limited,
* occupants can leave the works or be rescued by other means,
* the safety of rescue teams is taken into consideration".

For each of these essential requirements, an Interpretative Document was written by a specific Technical Committee of the Standing Committee set up by the CEC to follow the implementation of CPD.

In the Interpretative Document "safety in case of fire" [2], it is foreseen that the essential requirement may be satisfied as far as structural elements are concerned by:
* tests according to harmonised standards or EOTA (European Organization for Technical Approvals) guidelines or,
* harmonised calculation and design methods or,
* a combination of tests and calculations.

Testing methodology standards are mainly developed by CEN TC 127 (Technical Committee N° 127) and calculation methods (Structural Eurocodes) are developed by CEN TC 250. These sets of European standards, which contain the sum of European and world-wide knowledge, gathered during the last decades, in the field of fire resistance and more specifically on the behaviour of structures in fire, should lead to an uniform manner of assessing the fire resistance of structures throughout Europe.

In EC2 to EC6 and EC9, Parts 1.1 deal with normal design at room temperature and Parts 1.2 deal with structural fire design [4 to 9]. In Part 2.2 of Eurocode 1, the actions in case of fire [3] include both mechanical actions, given by the probable loads applied to a structure during a fire, and thermal actions, represented by the temperature increase in the air and due to a fire.

2. Mechanical Actions

As regards mechanical actions, it is commonly agreed that the probability of the combined occurrence of a fire in a building and an extremely high level of mechanical loads is very small. In this respect the load level to be used to check the fire resistance of elements refers to other safety factors than those used for normal design of buildings. The general formula to be used to calculate the relevant effects of actions is:

$$\sum \gamma_{GA} \cdot G_{k,j} + \psi_{1,1} \cdot Q_{k,1} + \sum \psi_{2,1} \cdot Q_{k,i} + \sum A_{d(t)} \qquad \text{(F.1)}$$

where:

$G_{k,j}$ = characteristic value of the permanent action ("dead load")
$Q_{k,1}$ = characteristic value of the main variable action
$Q_{k,i}$ = characteristic value of the other variable actions

γ_{GA} = partial safety factor for permanent actions in the accidental situation, [1,0] is suggested
$\psi_{1,1}$; $\psi_{2,i}$ = combination factors for buildings according to table 9.3 of ENV 1991-1 [10]
$A_{d(t)}$ = design value of the accidental action resulting from the fire exposure.

This accidental action is represented by:

- the temperature effect on the material properties and
- the indirect thermal actions created either by deformations and expansions caused by the temperature increase in the structural elements, where as a consequence internal forces and moments may be initiated, either by thermal gradients in cross-sections leading to internal stresses.

For instance, in a domestic, residential or an office building with imposed loads as the main variable action ($Q_{k,1}$) and wind or snow as the other variable actions, the formula is

$1{,}0\ G_k + 0{,}5\ Q_{k,1}$ since ψ_2 for wind and snow are equal to zero.

For a storage building the formula becomes

$1{,}0\ G_k + 0{,}9\ Q_{k,1}$.

When, in a domestic, residential or an office building, the main variable action is considered to be the wind load ($Q_{k,1}$ in the case) and the imposed load ($Q_{k,2}$ in this case) is the other variable action, the formula is

$1{,}0\ G_k + 0{,}5\ Q_k, 1 + 0{,}3\ Q_{k,2}$.

In the case of snow as the main variable action, the formula becomes

$1{,}0\ G_k + 0{,}2\ Q_{k,1} + 0{,}3\ Q_{k,2}$.

Generally this leads in the fire situation to a loading which corresponds to 50 to 70 % of the ultimate load bearing resistance at room temperature for structural elements.

3. Thermal Actions

Concerning thermal actions, a distinction is made between nominal fires and parametric fires.

Nominal fires are conventional fires which can be expressed by a simple formula and which are assumed to be identical whatever is the size or the design of the building. Nominal fires are mainly (see figure 1) the standard fire (ISO-834), the hydrocarbon fire reaching a constant temperature of 1100°C after 30 min, and the external fire (used only for external walls) reaching a constant temperature of 680°C after 30 min (see 4.2 of ENV 1991-2-2). They have to be used when it is required to prove that an element has the necessary level of fire resistance to fulfil national or other requirements expressed in terms of fire rating related to one of these nominal fires.

"Parametric fires" is a general term used to cover fire evolution more in line (compared to nominal fires) with real fires expected to occur in buildings. They take into account the main parameters which influence the growth and development of fires. In this respect the temperature-time curve (and subsequently the heat flux) varies when the size of the building or the amount or kind of fire load, varies.
This more realistic way of determining the thermal action due to an expected fire can only be used in association with an assessment by calculation methods. Due to the large variety of possible temperature-time curves in a building, the assessment method would have been very expensive if the only possibility was to test components in furnaces for each particular temperature-time fire curve.

In the current version of Part 2.2 of Eurocode 1, there are two methods of representing parametric fires:

* For internal elements (elements inside the building) simplified formulas can be used which take into account the following main parameters: the fire load, the opening factor $O = A_v \cdot \sqrt{h} / A_t$, (with A_v: area of vertical openings, h: height of vertical openings, A_t: total area of enclosure), and the thermal properties of the surrounding walls of the compartment (see 4.3 and Annex B of ENV 1991-2-2).

An example of the results of using these formulas with a fire load $q_{f,d} = 600$ MJ/m^2, and an opening factor varying from 0,02 m$^{1/2}$ to 0,20 m$^{1/2}$ is shown in figure 2 (a). However according to a research founded from 1987 to 1991 by ECSC [12], similar parametric temperature-time curves were established. Results obtained by this approach, for the same set of previous data, are shown in figure 2 (b), and seem to be more realistic.
Indeed the heating curves of figure 2 (a) show that the fire is ventilation-controlled [11] for all opening factors from 0,20 m$^{1/2}$ to 0,02 m$^{1/2}$, and that in the cooling phase the temperature-time curve is strictly linear!

On the contrary the heating curves of figure 2 (b) show that the fire is fuel-controlled for opening factors from 0,20 m$^{1/2}$ to 0,10 m$^{1/2}$ and becomes ventilation-controlled for smaller opening factors. Further more in the cooling phase the temperature-time evolution is curved!

** The temperature of structural elements outside the building can be evaluated by using a calculation method in which the maximum temperature in the compartment and in the flames going out of openings are calculated (see Annex C of ENV 1991-2-2).

As explained in (23) of the foreword of Part 2.2 of Eurocode 1, it is planned to introduce, in the final stage, a more general concept dealing with "natural fires" in order to permit the use of commonly agreed fire models [13, 14, 15].

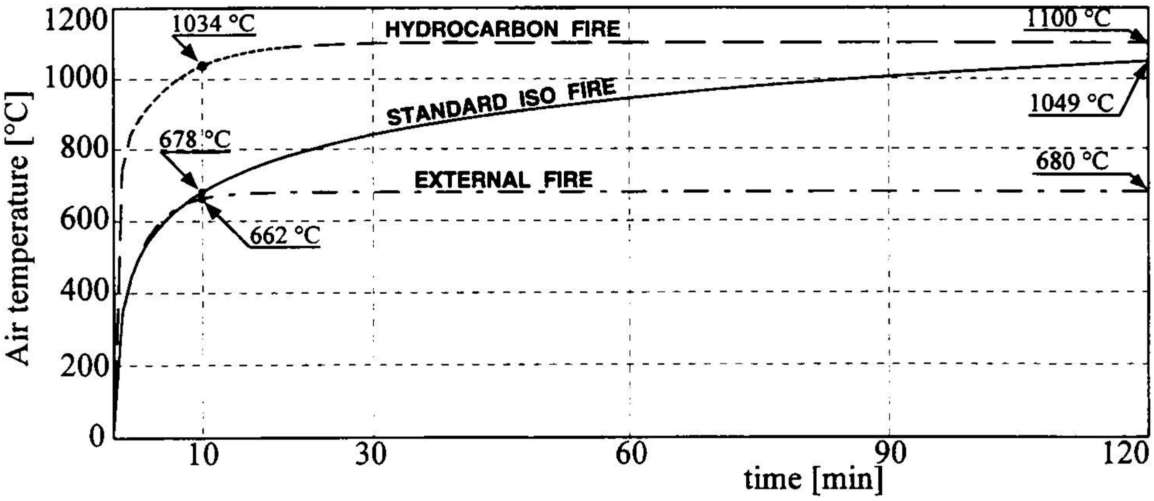

Fig. 1. Nominal temperature-time curves according to 4.2 of ENV 1991-2-2 [3]

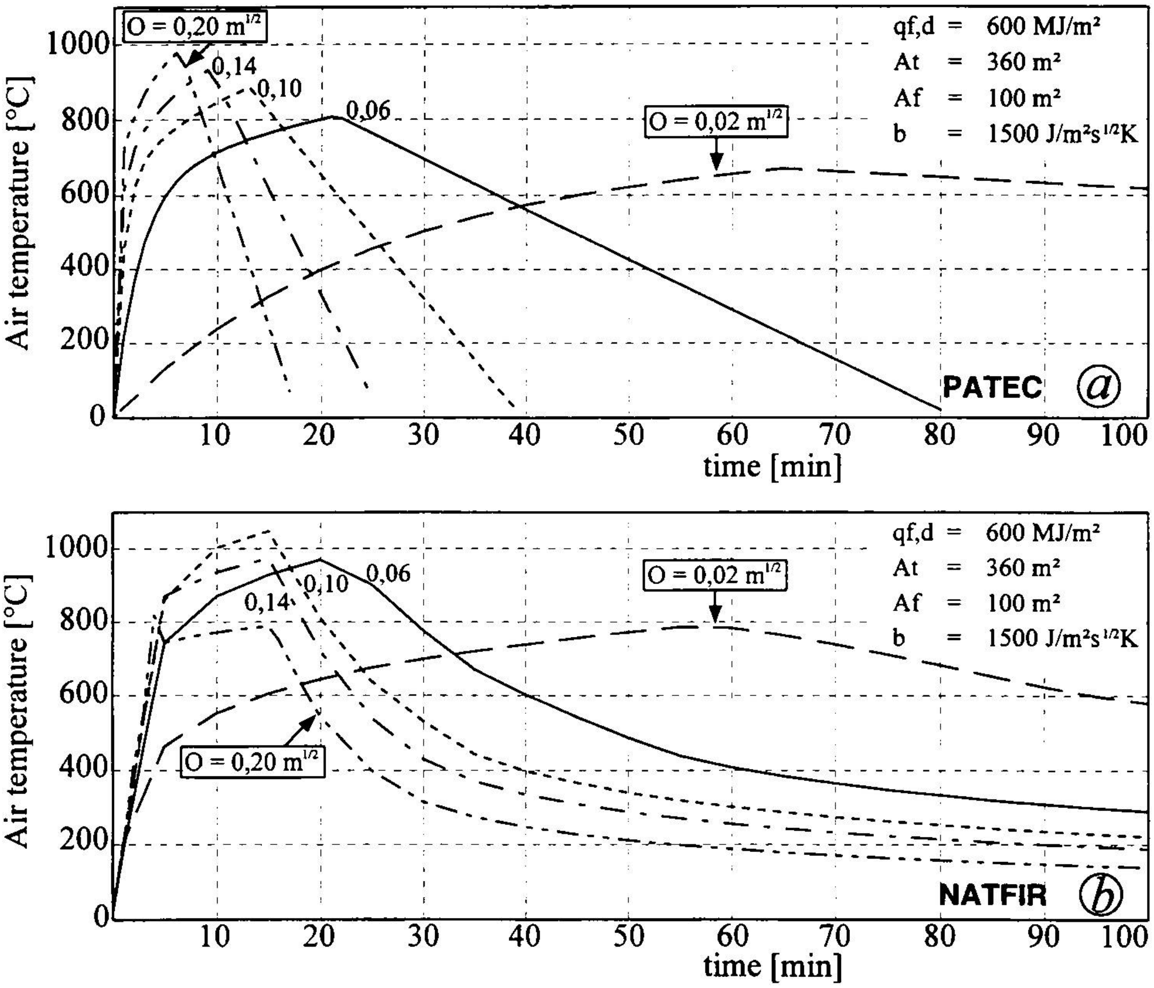

Fig. 2. Parametric temperature-time curves according to 4.3 and Annex B of ENV 1991-2-2 (see ⓐ) and following E.C.S.C. RESEARCH 7210-SA/112, Activity C1 [12], (see ⓑ).

4. Fire Load Densities

The fire load density q_d should be a design value either based on a fire load classification of occupancies, either determined specific for an individual project by performing a survey of fire loads from the occupancy.

The fire load density is one of the main parameters used in all existing fire models, as well the simple calculation models like the parametric fires (Annex B of ENV 1991-2-2), or the equivalent time of fire exposure (Annex E of ENV 1991-2-2) or any one-zone or two-zone fire models, as the advanced calculation models like multi-zone fire models or computational fluid dynamics (CFD) models [13, 14, 15].

The design fire load density is defined as

$$q_d = \gamma_q \cdot \gamma_n \cdot q_k \qquad \text{(D.1)}$$

where q_k is the characteristic fire load density either taken from a classification of occupancies like Annex 1 of SIA 81 [16], or established by calculation using equations (D.2), (D.3), (D.4) and table D.1 of ENV 1991-2-2.

The safety factor γ_q depends on the consequences of a failure and the frequency of a fire.

$$\gamma_q = \gamma_{q1} \cdot \gamma_{q2}, \text{ normally} \geq 1 \qquad \text{(D.1.1)}$$

Whereas the safety factor γ_{q1} related to the consequences of a failure is function of the size of the compartment under fire and of the number of storeys of the building (see figure 3), the safety factor γ_{q2} related to the frequency of fires is depending on the danger of fire activation and therefore is function of occupancies (see figure 4).

The differentiation factor γ_n is accounting for various active fire safety measures able to reduce the practical heating effect of the characteristic fire load density.

$$\gamma_n = \gamma_{n1} \cdot \gamma_{n2} \cdot \gamma_{n3} \cdot \gamma_{n4} \cdot \gamma_{n5} \leq 1 \qquad \text{(D.1.2)}$$

Referring to various national regulatory documents [16 to 19] and following (3) of D1 of ENV 1991-2-2, figure 5 was established showing that γ_n could be split up in different contributions due to the fire extinction effect of approved sprinklers γ_{n1}, the automatic fire detection γ_{n2}, the automatic fire alarm transmission γ_{n3}, the independent water supply for sprinklers γ_{n4} and the existence of a work fire brigade γ_{n5}.

By considering such active fire safety measures, the effect of the design fire load density q_d may be reduced down to 20 % of its initial value. The severity of the corresponding natural heating will of course drop in a significant way, whereas as well the safety of people as the safety of the building will be largely improved. Based on the previously given national regulatory documents [16 to 19] and on the ECSC Research "Natural Fire Safety Concept" [15], managed by ProfilARBED Research from 1994 to 1998, the comprehensive effect of all active fire safety measures should be included in the forthcoming EN 1991-2-2.

Surface of compartment (m^2)	Safety Factor γ_{q1}	
	One storey building	Building with several storeys
≤ 2500	1,00	1,25
5000	1,05	1,35
10000	1,10	1,45
20000	1,20	1,55
30000	1,25	1,60
60000	1,35	/
120000	1,50	/

Fig. 3. Safety factor γ_{q1} according to DIN 18230-1 [19] in function of the size of the compartment under fire and for different types of building

Safety factor γ_{q2}	Danger of Fire Activation	Examples of Occupancies
0,85	small	artgallery, museum
1,00	normal	residence, hotel, paper industry
1,20	mean	manufactory for machinery & engines
1,45	high	chemical laboratory, painting workshop
1,80	very high	manufactory of fireworks or paints

Fig. 4. Safety factor γ_{q2} according to SIA 81 [16] in function of the occupancy of the building.

Official Document		γ_{ni} Function of active Fire Safety Measure							$\gamma_n = \gamma_{n1}\cdot\gamma_{n2}\cdot\gamma_{n3}\cdot\gamma_{n4}\cdot\gamma_{n5}$
		Automatic Water Extinguishing System	Automatic Fire Detection and Alarm	Automatic Alarm Transmission to Fire Brigade	Independent Water Supplies			Work Fire Brigade	
					0	1	2		
Title	Date of Publication	γ_{n1}	γ_{n2}	γ_{n3}	γ_{n4}			γ_{n5}	$\gamma_n^{max} = \gamma_{n1}\cdot\gamma_{n2}$
ENV 1991-2-2	1995	0,60	/	/	/			/	0,60
DIN 18230-1 Project	1995	0,60	0,90	/	/			0,6 1,0	0,32 0,54
New Zealand Limit State Des. Guide	1993	0,60	/	/	/			/	0,60
ANPI (B)	1988	0,58 ❄	0,82	included in ❄	1,0	0,86	0,65	0,5 1,0	0,16 0,48
SIA 81	1984	0,59 0,50	0,83	0,83 1,0	/			0,67 1,0	0,23 0,49

Fig. 5. Differentiation factor γ_n accounting for various active fire safety measures like fire extinction by sprinklers γ_{n1}, automatic fire detection γ_{n2}, automatic fire alarm transmission γ_{n3}, independent water supply for sprinklers γ_{n4} and the existence of a work fire brigade γ_{n5}, in function of different regulatory documents [3, 16 to 19].

5. The Equivalent Time of Fire Exposure

The following approach, given in Annex E of ENV 1991-2-2, allows to use realistic fire conditions depending on the design fire load density $q_{f,d}$ and on the ventilation, even when the design of members is by tabulated data or simplified rules related to the standard fire (see ENV 1992-1-2, ENV 1993-1-2, ENV 1994-1-2).

In fact by definition the equivalent ISO time is the time during which a given structural element has to be submitted to the ISO fire curve in order to obtain, in that element, the same maximum temperature than the natural fire curve would have produced. It was when applying this principle to concrete cross-sections, with reinforcing bars protected by a 3 cm thick concrete layer, that equation (E.1) was established.

$$t_{e,d} = q_{f,d} \cdot k_b \cdot w_f \qquad \text{(E.1)}$$

The equivalent ISO time $t_{e,d}$, formulated in this way with k_b and w_f given in (4) and (5) of Annex E, is material independent, but $t_{e,d}$ should in fact be and in reality is, material dependent.

Indeed when using Annex B, giving parametric temperature-time curves according equations (B.1) to (B.6), and applying these natural heating curves as well as the standard fire to different cross-sections, the non linear finite element code CEFICOSS allowed to establish the differential & transient temperature fields in those cross-sections [22].

* The conclusion drawn when considering the previous definition of the equivalent time was:

- The two methods, Annex E and Annex B + CEFICOSS, lead to similar equivalent times for concrete cross-sections or sections made of protected profiles.
- However if the cross-section is an unprotected steel profile, these two methods give contradictory results. In fact equation (E.1) of Annex E gives too high values for $t_{e,d}$, or finally leads to a much too severe heating up of the steel section under a given natural fire. Indeed,
  if A_v (or O) $\nearrow$, $t_{e,d} \nearrow$ according to Annex B
  but $t_{e,d} \swarrow$ according to Annex E.

Therefore equation (E.1) may be improved to apply to unprotected steel:

$$t_{e,d} = \left(q_{f,d} \cdot k_b \cdot w_f\right) k_c \qquad \text{(E.1.1)}$$

with k_c correction factor function of the material composing structural cross-sections and defined in figure 6.

** For composite construction elements, the equivalent time as defined before, based on an unique temperature equivalence, is not valid anymore. Indeed such a procedure would depend on the considered element, beam or column, and on the considered point in the cross-section. When applying this method to the composite frame tested under natural fire conditions in Braunschweig April 12 and 24, 1989 [20], it was found that the equivalent ISO time $t_{e,d}$ would scatter from 42 to 80 minutes (see figure 7).

In fact for composite structures the equivalence between a natural fire and the ISO-fire has to be based on the equivalence of the load bearing capacity. This was done for the previously named composite frame test [20], and the equivalent ISO time t $_{e,d}$ obtained was 46 minutes (see figure 8)!

Cross section Material	Correction factor k_c
Reinforced Concrete	1,0
Protected Steel	1,0
Not protected Steel	13,7 · O

Fig. 6. Correction factor k_c , to be applied to the equivalent time $t_{e,d}$ of Annex E, in order to cover various cross-sections. (O is the opening factor defined in Annex B in $m^{1/2}$)

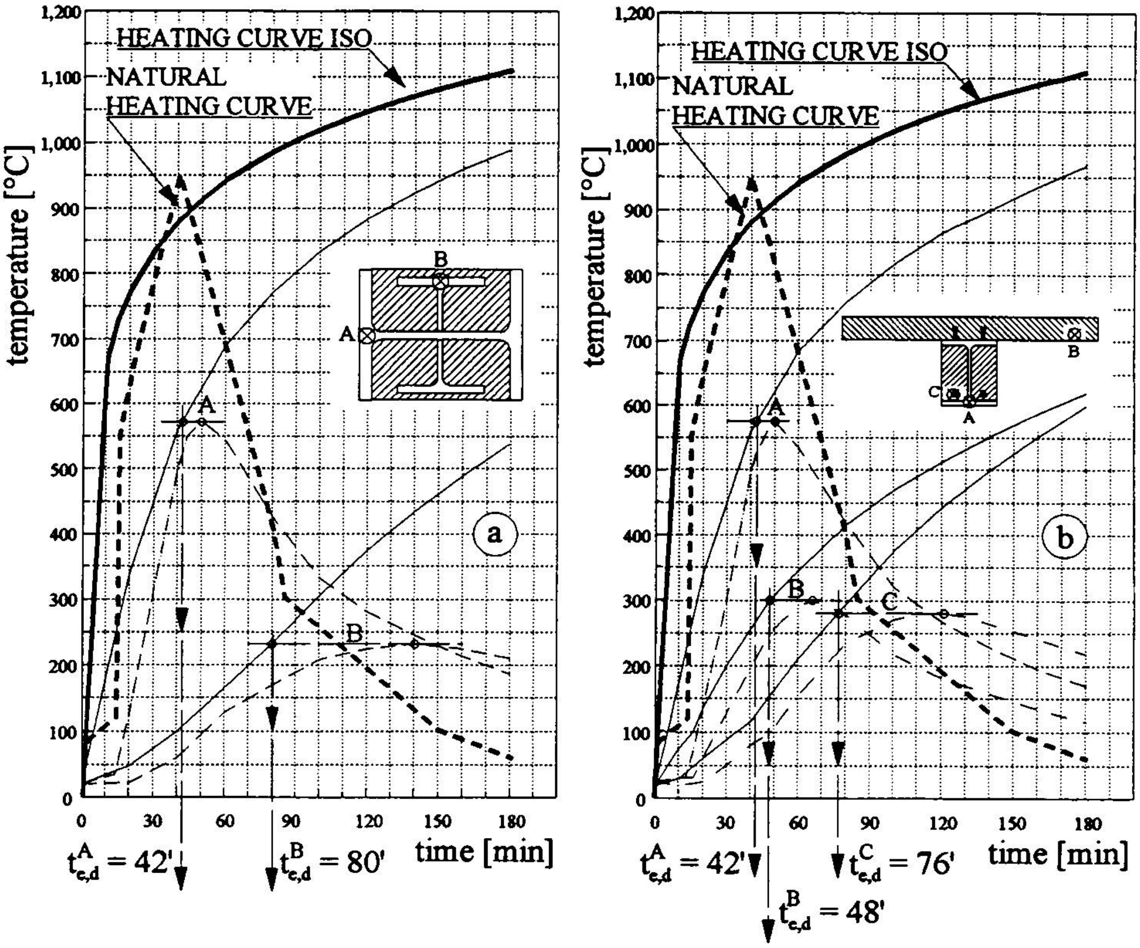

Fig. 7. Temperatures calculated by CEFICOSS in the composite column ⓐ and the composite beam ⓑ for the ISO heating (——) or the natural heating (- - -) according to the Braunschweig tests on April 12 and 24, 1989 [20].

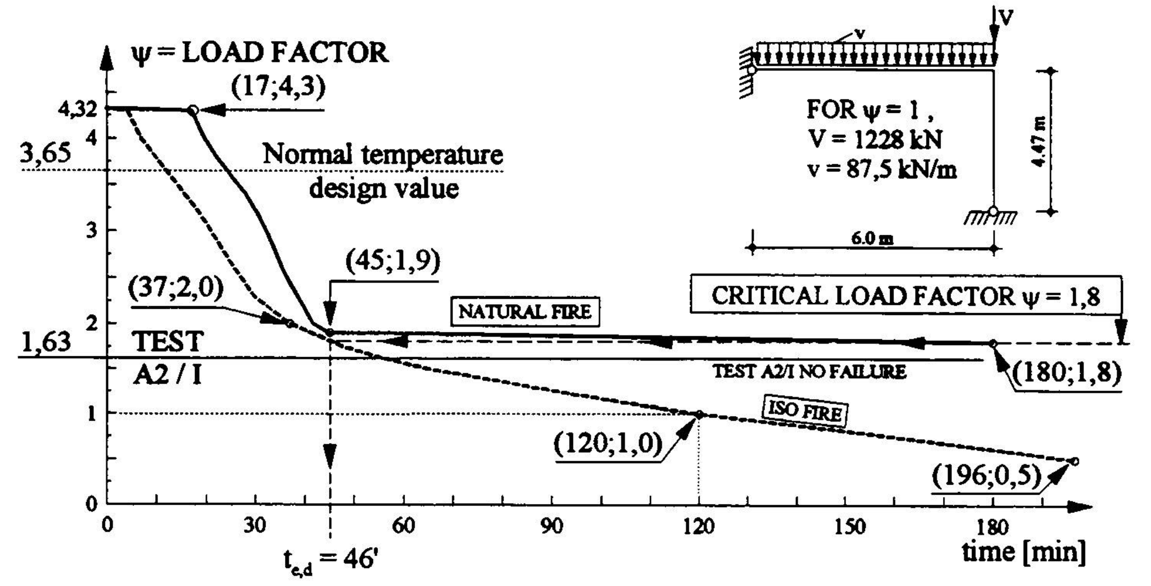

Fig. 8. Composite frame A2-I / Fire resistance calculated by CEFICOSS in function of ψ, for the ISO-Fire and the Natural Fire defined in Figure 7 [20]

6. Conclusions

The main aspects of the present ENV 1991-2-2, officially issued by C.E.N. on February 9, 1995, have been highlighted. In some domains like that of parametric fires, of two-zone and multi-zone fire models, of the equivalent ISO time, and of the consideration of active fire safety measures, research is proceeding. Efforts need to be undertaken to determine the properties of combustible materials, their combustion behaviour and net calorific values, and to clarify the problem of the rate of heat release RHR in function of time [21, 22, 23].

Undoubtedly it will be possible to improve in a significant way EN 1991-2-2, the next version of the present prestandard ENV 1991-2-2, which even now allows the use of more realistic fire models.

7. Bibliography

[1] EC; Construction Products Directive, dated 21.12.1988, 89/106/EEC. Official Journal of the European Communities, N° L40/12, Luxembourg, 11.02.1989.

[2] EC; Interpretative Document N°2, Essential Requirement "Safety in case of fire". Official Journal of the European Communities, N° C62/23, Luxembourg 28.02.1994.

[3] CEN; ENV 1991-2-2, Eurocode 1 - Basis of design and actions on structures, Part 2.2 - Actions on structures exposed to fire. CEN Central Secretariat, Brussels, DAV 09.02.1995.

[4] CEN; ENV 1992-1-2, Eurocode 2 - Design of concrete structures, Part 1.2 - Structural fire design. CEN Central Secretariat, Brussels, Final Draft Sept. 1995.

[5] CEN; ENV 1993-1-2, Eurocode 3 - Design of steel structures, Part 1.2 - Structural fire design. CEN Central Secretariat, Brussels, Final Draft July 1995.

[6] CEN; ENV 1994-1-2, Eurocode 4 - Design of composite steel and concrete structures, Part 1.2 - Structural fire design. CEN Central Secretariat, Brussels, DAV 30.10.1994.

[7] CEN; ENV 1995-1-2, Eurocode 5 - Design of timber structures, Part 1.2 - Structural fire design. CEN Central Secretariat, Brussels, DAV 30.11.1994.

[8] CEN; ENV 1996-1-2, Eurocode 6 - Design of masonry structures, Part 1.2 - Structural fire design. CEN Central Secretariat, Brussels, Final Draft June 1995.

[9] CEN; ENV 1999-1-2, Eurocode 9 - Design of aluminium alloy structures, Part 1.2 - Structural fire design. CEN Central Secretariat, Brussels, First Draft May 1995.

[10] CEN; ENV 1991-1, Eurocode 1 - Basis of design and actions on structures, Part 1 - Basis of design. CEN Central Secretariat, Brussels, DAV 30.10.1994.

[11] WICKSTRÖM, U.; Application of the standard fire curve for expressing natural fires for design purposes. ASTM STP 882, pp. 145-159, 1985.

[12] SCHLEICH J.B., SCHERER M.; Compartment temperature curves in function of opening factor and fire load. ECSC Research 7210-SA/112, Activity C1 / RPS Report N°08/90, Luxembourg, 02.02.1991.

[13] SCHLEICH J.B., CAJOT L.G.; Natural fires in closed car parks. ECSC Research 7210-SA/518 etc., B-E-F-L-NL, 1993-96.

[14] SCHLEICH J.B., CAJOT L.G.; Natural fires in large compartments. ECSC Research 7210-SA/517 etc., B-E-F-L-NL, 1993-96.

[15] SCHLEICH J.B., CAJOT L.G.; Competitive steel buildings through natural fire safety concept. ECSC Research 7210-SA/522 etc., B-D-E-F-I-L-NL-UK & ECCS, 1994-98.

[16] SIA; Brandrisikobewertung, Berechnungsverfahren. Dokumentation SIA 81, Zürich, 1984.

[17] ANPI; Evaluation des risques. Association Nationale pour la Protection contre l'Incendie, Ottignies, 1988.

[18] SNZ; New Zealand Structural Steelwork Limit State Design Guide. HERA Report R4-74 (I), Manukau City, 1993.

[19] DIN; Baulicher Brandschutz im Industriebau - Teil 1: Rechnerisch erforderliche Feuerwiderstandsdauer. DIN 18230-1, Beuth Verlag GmbH, Berlin, 1995.

[20] SCHLEICH J.B., LICKES J.P.; Simulation of test frames A2/I and A2/II. ECSC Research 7210-SA/112, Activity A2/B1 / RPS Report N°04/90, Luxembourg, 26.11.1990.

[21] TWILT L. & Co; Input data for the natural fire design of building structures. IABSE Colloquium, Basis of Design and Actions on Structures, Delft, 27/29.03.1996.

[22] FRANSSEN J.M. & Co.; Parametric temperature-time curves and equivalent time of fire exposure. IABSE Colloquium, Basis of Design and Actions on Structures, Delft, 27/29.03.1996.

[23] CAJOT L.G., & Co.; Influence of the Active Fire Protection Measures. IABSE Colloquium, Basis of Design and Actions on Structures, Delft, 27/29.03.1996.

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