Efectis France | Espace Technologique Bâtiment Explorer - Route de l'Orme des Merisiers
91190 SAINT-AUBIN | France
+33 1 60 13 83 82 | france@efectis.com

Guidance document

Efectis EFR-21-001771:2026

Regarding the

Evaluation of the performance for insulated steel sections exposed to natural fires

Date of issue:	08 April 2026
Number of pages:	24

FOREWORD

The fire performance of structures is conventionally evaluated with respect to standard fire curves. Such standard heating regimes do not match the typical behaviour of compartment fires, commonly denoted as ‘natural fire curves’, and consisting mainly in a growth phase followed by a fully developed phase and finally a decay phase. In performance based code application, modelling is often used to deal with natural fire curve, while existing test standards only provide for the evaluation of the contribution of passive fire protection systems when exposed to the standard fire curve.. The present guidance fills the gap.

Existing fire test standards mostly consider standard furnace fire curves as defined in EN 1363-1 and sometimes EN 1363-2.
However, these standard curves do not reproduce some important observed effects of real fires, such as differences in slow or fast heating, lower or higher maximum temperatures, cooling phase, combustion rate, etc.

Developing reliable material property databases for structural steel protection validated for more realistic fire scenarios such as natural fires is crucial as input in fire simulation tools to to accurately assess the safety level.

For configurations that deviate from the initial standard fire test data, the thermal properties derived using standard fire curve methods could not be accurate as the protection system can behave differently.
For example, timeline and size of cracking, joint opening, detachment and degradation of material, degradation due to higher temperature exposure, or inadequate thickness due to longer fire exposures, could differ.
Capturing the behaviour of materials during the cooling phase is therefore crucial in fire design, because failure of the passive fire protection and the structural element can occur during that cooling phase and, even in the absence of failure, accurate prediction of the residual capacity is desirable.

The lack of guidance and standardization on material properties under natural fires greatly complicates the task of conducting performance-based fire designs.

This document fills the gap by providing guidance on how to evaluate the performance of passive fire protection systems when exposed to natural fire curves. The general approach chosen in this document is in line with EN 13381-4, but guidance is given on how to accommodate natural fire curves in fire testing as well as in the analysis of the results.

CONTENT

1. REVISION HISTORY

Revision	Date of issue	Writer	Approver
First issue	08/04/2026	Clifford CHINAYA	Daniel JOYEUX

2. SCOPE

When designing the fire resistance of a loadbearing structure of a building, an engineer can choose different approaches. The most commonly used approach is based on a standard fire curve, as described in e.g. ISO, EN and ASTM standards in very similar ways. Using a standard fire curve, well-elaborated methods are available to verify the loadbearing capacity of loadbearing steel structures without fire protection, as well as well-elaborated methods to characterize the performance of passive fire protection products in case fire protection is needed to meet the fire resistance requirements.

However, when it comes to the design of passive fire protection for steel structures exposed to natural or parametric fire curves, no standardized methods are available. By absence of standards, engineers either make assumptions based on limited data or avoid this approach altogether. Also, authorities and regulators are in many cases reluctant to admit the use of passive fire protection in combination with natural or parametric fire curves because of the lack of standardization and the lack of evidence of the performance of fire protection systems.

To close this gap, the present protocol specifies a method for determining the contribution of fire protection systems to the fire resistance of structural steel members, which can be used as beams and columns, when exposed to natural fires.

It considers only sections without openings in the web.
It is not directly applicable to structural tension members, meaning solid bars or rods.

The protocol is designed to cover a range of selected:
- Thicknesses of the fire protection material applied,
- Steel sections, characterised by their section factors
- Natural fire curves.

This protocol includes the fire test procedures, which specify the tests which should be carried out to determine the ability of the fire protection system to remain coherent and attached to the steelwork, and to provide data on the thermal characteristics of the fire protection system when exposed to natural fire curves.

This protocol is based on the existing standard EN 13381-4 and especially its annex E.3 detailing the calculation of the variable thermal conductivity of the fire protection system which can be used as direct input to the calculation of fire resistance of steel structural members in accordance with the procedures given in EN 1993-1-2.

This protocol applies to fire protection materials that have already been tested and assessed in accordance with EN 13381-4. i.e. this document cannot be used in isolation.

The protocol consists into 3 steps:
- Firstly, performing fire tests in standardized fire resistance furnaces using standard fire curve and specific “simulated” curves aiming to define the limits of the target range of natural fire curves,
- Then, carrying out a numerical analysis to define the variable thermal conductivity of the protection system (approach similar to that of annex E.3 of the EN 13381-4 standard),
- Finally, performing a natural (wood crib) fire test with a completely different fire curve and selection of test specimens to confirm the analysis.

3. NORMATIVE REFERENCES

Standard	Title
EN 1363-1:2020	Fire resistance tests - Part 1: General requirements
EN 1363-2:1999 + C1:2001	Fire resistance tests - Part 2: Alternative and additional procedures
EN 13381-4:2013	Test methods for determining the contribution to the fire resistance of structural members - Part 4: applied passive protection to steel members

4. TEST EQUIPMENTS

4.1. For “simulated” fire tests

4.1.1. General

The furnace and test equipment shall conform to that specified in EN 1363-1.

When a specific fire curve is used, without any indication concerning the deviation tolerances, the standard deviation tolerances mentioned in EN 1363-1 shall be used.

4.1.2. Furnace

The furnace shall permit the dimensions of the test specimens to be exposed to heating, as specified in Clause 6 of the standard EN 13381-4 and their installation upon or within the test furnace to be as specified in Clause 7 of the standard EN 13381-4.

4.1.3. Loading equipment

Loading shall be applied according to EN 1363-1. The loading system shall permit loading to be applied to beams as specified in 5.2.1 of the standard EN 13381-4 and to columns as specified in 5.2.3 of the standard EN 13381-4.

4.2. For natural fire tests

4.2.1. General

The test chamber shall conform to that specified in Clause 4.2.2 of this document.
The test equipment shall conform to that specified in EN 1363-1.

4.2.2. Test chamber

The test chamber shall permit the dimensions of the test specimens to be exposed to heating, as specified in Clause 6 of the standard EN 13381-4 and their installation upon or within the test furnace to be as specified in Clause 7 of the standard EN 13381-4.

The test chamber shall be designed using material with adequate properties to be able to fulfil the expected natural fire curve.

The test chamber shall contain openings with adjustable surface area, in order to control the supply and exhaust of air inside the chamber.

Example of ventilation condition – front face of the test chamber

4.2.3. Loading equipment

Loading shall be applied according to EN 1363-1. The loading system shall permit loading to be applied to beams as specified in 5.2.1 of the standard EN 13381-4 and to columns as specified in 5.2.3 of the standard EN 13381-4.

5. TEST CONDITIONS

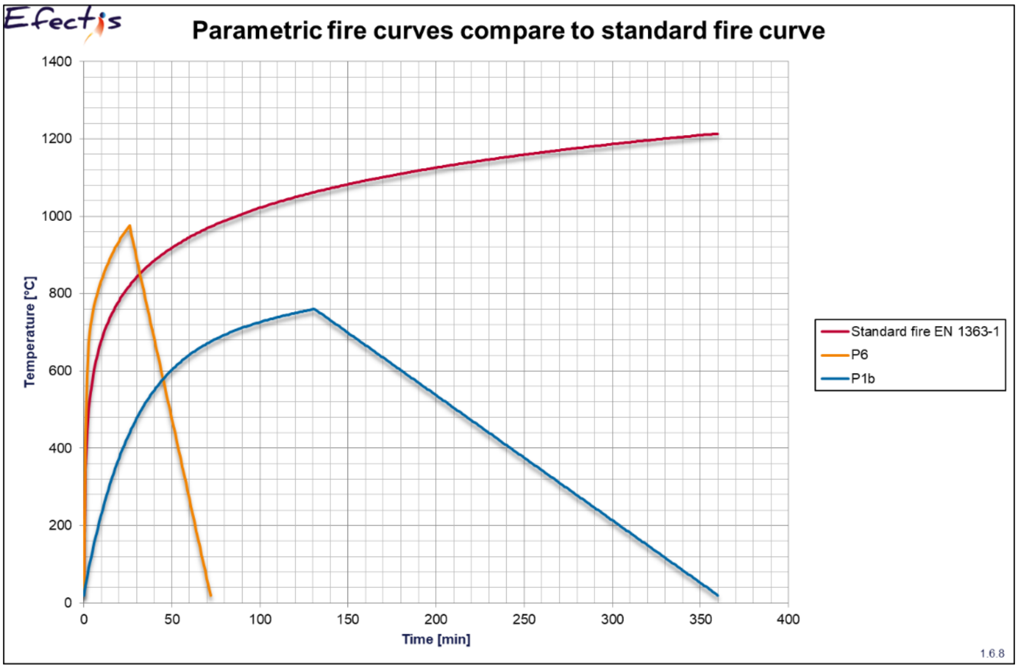
5.1. General

A number of short steel, I or H or hollow test sections, protected by the fire protection system, are heated in a furnace (“simulated” fire) or test chamber (natural fire) to expose the specimens to fire curve which could be different from the standard curve specified in EN 1363-1 depending on the scope to cover.

The parametric fire curves must be defined according to EN 1991-1-2 and potential national annex.

The test program must be done for both:

- A fire curve with faster temperature increase, shorter duration and a fast cooldown phase (e.g. “P6” *)
- A fire curve with slower temperature increase, longer duration and a long cooldown phase (e.g.“P1b” *)



Examples of parametric fire curve

** The curve names "P1-b" and "P6" are working titles. A clearer name could be, e.g. "long slow parametric fire curve" and "short intense parametric fire curve". The curves given in the graph above are examples.*

Analytically, the rise phases are given by the following equation:

$$\theta_g(t) = 20 + 1325\,(1 - 0{,}324\ e^{-0.2 \times \Gamma \times t} - 0{,}204\ e^{-1{,}7 \times \Gamma \times t} - 0{,}472\ e^{-19 \times \Gamma \times t})$$

and the decay phases are linear with a slope define for each curve by t_{max} and time to reach ambient condition.

In this equation, t is the time in hours and the parameter for each curve are shown in following table.

Coefficient	Curve P1b	Curve P6
Γ	0.12	2.83
t_{max} [minutes]	131	26
Ambient temperature [°C]	20	20
Ambient condition reached at [minutes]	360	72

Coefficients used to plot the Pcurves used in the example

In any case, the selected fire curve used during tests on furnace will define the scope of the analysis.

Loaded and unloaded beams or columns that are likewise heated provide information on the ability of the fire protection system to remain intact and to adhere to the steel test sections (stickability).

The method for testing loaded beams in this part of the test method is designed to provide maximum deflection (span/30) under the influence of load and heating.

It is recommended to continue the test until the steel temperature reaches the maximum temperature on each steel profile.

When several test specimens are tested simultaneously, care shall be taken to ensure that each sample is adequately and similarly exposed to the specified test conditions.

The procedures given in EN 1363-1 shall be followed in the performance of this test unless specific contrary instructions are given in this standard.

5.2. Support and loading conditions

5.2.1. Loaded beams

Each loaded beam test specimen shall be simply supported, and allowance shall be made for free expansion and vertical deflection of the beam.

The beam shall not be provided with additional torsional restraint except where deemed necessary as defined in 6.3.1 of the standard EN 13381-4.

The loading shall be applied using methods allowed in the standard EN 13381-4.

The ends of the loaded beams outside the furnace shall be insulated with a suitable insulation material.

5.2.2. Loaded columns

Loaded columns shall be tested according to standard EN 13381-4.

5.2.3. Unloaded beams and columns

Unloaded beams and columns are supported according to EN 13381-4.

5.3. Loading

The loaded beam specimens shall be subjected to a total load which represents 60% of the design moment resistance, according to EN 1993-1-1, calculated using the steel yield strength from the batch certificate of conformity or an measured value of those specimens.

The load applied shall be the calculated total load less the dead weight of the beam, concrete topping and fire protection material etc.

The method of loading shall be by a system that will produce a bending moment, which is uniform over at least 20% of the span of the beam around mid-span.

The loaded column shall be subjected to a load which represents 60% of the design buckling resistance, according to EN 1993-1-1, calculated using the steel yield strength from the batch certificate of conformity or an measured value of the specimen. Details of the calculation made to define the test loads shall be included in the test report.

Loaded steel test sections shall be tested in accordance with EN 1365-3 or EN 1365-4 subject to any amended or additional requirements of this standard.

5.4. Natural fire test

Natural fire test shall be reached using timber cribs.
Timber cribs design shall be calculated previously, using predefined ventilation conditions, in order to reach a specific fire curve that shall be different from all other fire curves used during furnace tests.

Depending on the desired fire curve (rapid rise but limited duration or, on the contrary, slow rise and long duration), different parameters of the wood crib must be adjusted as illustrated in the following figure.

Together with the natural ventilation of the fire room, different combustion regimes within the wood crib must be considered in order to produce and maintain the desired fire curve. To achieve this, the dimensions and arrangement of the wood sticks composing the crib must be evaluated to reach a combustion regime controlled either by:

- The porosity of the crib, illustrating the maximum flow rate of air and combustion products through the air holes in the crib; this governs for tightly packed cribs and ensures a quite slow and long lasting combustion, and leads to large stick thickness D and reduced stick clear spacing S,

or by

- The burning surface of the sticks, depending on the natural limit of stick surfaces burning freely; this limit applies to cribs with wide inter-stick spacings, ensuring a quite rapid and intense combustion, and leads to reduced stick thickness D and larger stick clear spacing S.

The duration of the fire through the combustion of the wood crib is also function of the mass of wood available. The height of the wood crib (h_c) must thus be adjusted, depending on the individual height of each wood stick as well as the number of stacked sticks.

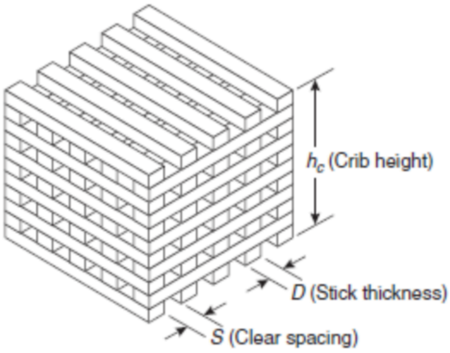


Illustration of a timber crib

6. TEST SPECIMENS

6.1. General

This section only refers to tests performed on a furnace.

The set of test specimens is an extension to test package 3 of Clause 6.6.1 of the standard EN 13381-4 which include 2 loaded beams, 2 reference beams and 13 unloaded short columns.

For an analysis of the contribution of the fire protection system to the fire resistance for steel structures exposed to natural fire curves,

- Test package 3 shall be tested in accordance with the standard EN 13381-4 (i.e. with the standard fire curve)
- The same specimens shall be tested in accordance with the principles of EN 13381-4 but employing a parametric curve to be chosen depending on the scope to cover.

It is essential that the range of section factors and fire protection thicknesses do not deviate from the ranges used during the tests according to EN 13381-4.

The specimens and the protection shall respect the requirements of the standard EN 13381-4:

- Size of the test specimens (Clause 6.2 of the standard EN 13381-4),
- Construction of steel test specimens (Clause 6.3 of the standard EN 13381-4),
- Composition of steel sections (Clause 6.4 of the standard EN 13381-4),
- Properties of fire protection materials (Clause 6.5 of the standard EN 13381-4).
- Requirements concerning the joints of the protection board.

6.2. Selection of test specimens

6.2.1. Sections required for correction for stickability

At least a loaded beam and a reference beam shall be tested for each of the fire curves which define the limit of the scope.

For tests done with the conventional fire curve, the selection is carried out according to the standard EN 13381-4.

Tests using “simulated” or natural fire curve shall be performed with an appropriate thickness of protection in order to reach the failure of the loadbearing capacity of the loaded beam.

The appropriate thickness of protection can be estimated using the results of the preliminary assessment, using the “variable λ approach”, of the protection system according to the test package tested in accordance with the standard EN 13381-4 considering a critical steel temperature around 500-550°C. If assessment according to the standard EN 13381-4 was done using a different method:

- Perform a new analysis with the method “variable λ approach” as defined in annex E.3 of the standard EN 13381-4,

OR

- Use the minimum thickness of the protection system

The section of the loaded beams and their reference beam shall be done according to the clause 6.6.2 of the standard EN 13381-4.

6.2.2. Sections required for thermal analysis

The sections to be tested shall be selected to remain in the range of protection thickness and section factor defined in the assessment done according to the standard EN 13381-4.

The set of short elements to be tested depends on the parametric fire curve. The paragraphs 6.2.2.1 and 6.2.2.2 give examples of profiles selection for the parametric fire curve described in paragraph 5.1.

6.2.2.1. Fire with fast growth and high maximum temperature (curve P6)

The following table presents the matrix of a suitable package of unloaded elements for a fire curve with fast growth and high maximum temperature:

Section range factor (K_s)	Thickness range factor (K_d)			
	0 (d_{min})	0.2 to 0.5	0.5 to 0.8	1 (d_{max})
0 (s_{min})	✓			
0.2 to 0.5	✓	✓		
0.5 to 0.8	✓		✓	
1 (s_{max})	✓		✓	

This matrix can be considered as being the minimum specimens to be tested.

6.2.2.2. Fire with slow growth and low maximum temperature (curve P1b)

The following table presents the matrix of a suitable package of unloaded elements for a fire curve with slow growth and low maximum temperature:

Section range factor (K_s)	Thickness range factor (K_d)			
	0 (d_{min})	0.2 to 0.5	0.5 to 0.8	1 (d_{max})
0 (s_{min})	✓	✓		
0.2 to 0.5	✓	✓	✓	✓
0.5 to 0.8	✓		✓	✓
1 (s_{max})	✓		✓	✓

This matrix can be considered as being the minimum specimens to be tested.

7. INSTALLATION OF THE TEST SPECIMENS

All the test specimens shall be installed as described in clause 7 of the standard EN 13381-4.

Exception can be authorized concerning the requirement of the furnace load describes in clause 7.6 of the standard EN 13381-4. The main objective remains to respect the fire curve and associated deviation.

8. CONDITION OF THE TEST SPECIMENS

All test specimens, their components and any test samples taken for determination of material properties shall be conditioned in accordance with EN 1363-1.

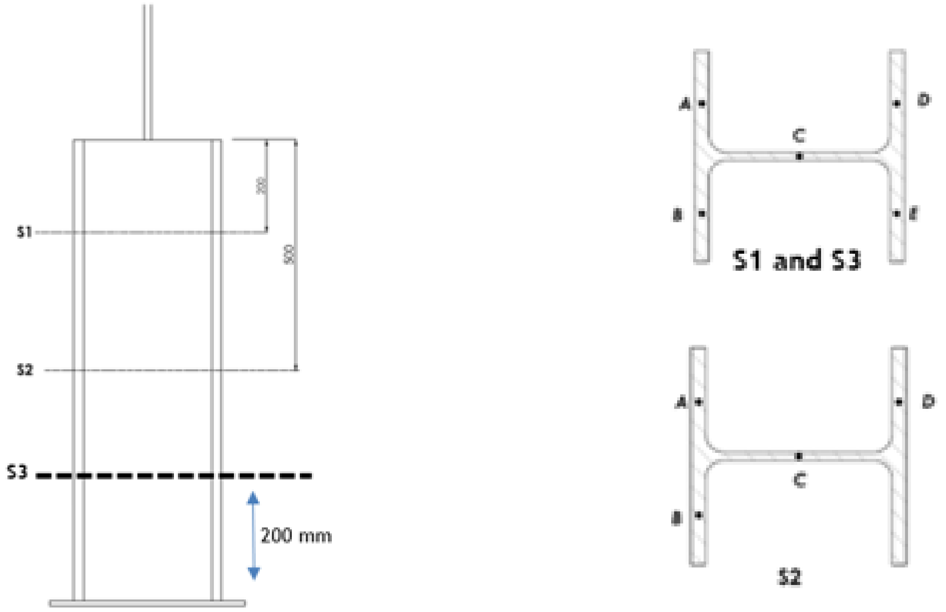
As the natural fire test might be performed with external condition, the test report should mention when the specimens were installed outside.

In case of testing in an outdoor test facility, influence of the environmental conditions on the fire protection product should be avoided; for example, it should not be exposed to conditions that may change the moisture content of the material.
The storage of the tested specimens outside should be limited.

9. APPLICATION OF INSTRUMENTATION

The entire instrumentation, meaning the furnace temperature and pressure, the temperature of specimens, the deflection of loaded beam and measurement of load, shall be done as described in clause 9 of the standard EN 13381-4.

During the natural fire test, and on short columns only, a third section S3 of thermocouples can be added as show below.



10. TEST PROCEDURE

The test procedure shall be done according to the clause 10 of the standard EN 13381-4 with the following additional requirements:

- The scan intervals shall not exceed 10 seconds,
- The cooling down phase must be recorded too, still with a maximum scan interval of 10 seconds

Recording of the cooling down phase is essential, as the maximum steel temperature of a protected element will normally be reached during this phase of the fire curve. This can occur in two modes:

- Due to thermal inertia, the temperature of the steel inside the fire protection lags behind, and/or
- Due to physical and/or chemical changes of the fire protection product, during cool down the product detaches from the steel and leaves the steel (partially) unprotected, at a time that the furnace temperatures are still sufficiently high to increase the steel temperature.

For this reason, the test shall not be terminated before the average furnace temperature is lower than the lowest of all section's average steel temperatures.

For natural (wood cribs) fire test, ignition of the fire shall be done with flammable liquid, like heptane for example, in a metallic tray. The surface and quantity of flammable liquid must be calculated in a way its combustion won't generate a fire temperature too far from the natural (wood cribs) fire curve to follow.

11. TEST RESULTS

The acceptability of the test results and the presentation of the test results shall be done according to the clause 11 of the standard EN 13381-4

12. TEST REPORT

The test report shall include the statements mentioned in clause 12 of the standard EN 13381-4 with the following requirements:

- For natural (wood cribs) fire test performed in an outdoor facility only, the date when the specimens are installed in the outside test chamber
- For natural fire test only:
  - a full description of the target fire curve with its associated limits
  - a full description of the timber cribs
  - a full description of the cribs ignition method
  - a full description of the ventilation conditions

13. ANALYSIS

13.1. General

The analysis of the data obtained from the tests performed with the different fire curves must be considered and should be done using the following main steps:

- Correct the time to reach each design temperature for all unloaded short element using the loaded beams and their references,
- Perform the variable thermal conductivity analysis based on annex E.3 of standard EN 13381-4* with some minor adaptation for this specific case** using the temperature of all unloaded short elements (all means all specimens tested for all the fire curve used),
- Compare the simulated time to reach each design temperature to the corrected time to fit acceptability criteria.

** note that formula used in paragraph E.3 of standard EN 13381-4 is the same as formula 4.27 of Eurocode EN 1993-1-2:2005.*
*** adaptation must be done as the standard EN 13381-4 only concern the standard fire curve which has no cooling down phase. Necessary modifications are applied directly in this chapter*

13.2. Temperature data

The steel temperature for the analysis purposes shall be:

- For loaded beams and their reference, the characteristic temperature as defined in clause 3.1.11 of the standard EN 13381-4: (mean temperature +maximum temperature)/2 with mean temperature calculated as defined below,
- For unloaded specimens, the mean temperature of each section calculated in accordance with clause 3.1.12 of the standard EN 13381-4:
  - for I and H section beams as the mean of the upper flange plus the mean of the web plus the mean of the lower flange divided by three;
  - for I, H and hollow section columns as the sum of the means of each measuring station divided by the number of measuring stations;
  - for hollow section beams as the mean of the sides plus the mean of the bottom face divided by two

13.3. Correction for discrepancy in stickability

13.3.1. Calculation of all correction factors

The correction of the data is based on annex D of the standard EN 13381-4.

To take into account the stickability performance of the product, the data for the short sections has to be corrected against the loaded beams or loaded columns depending upon the selected test programme.

The correction factor *k* is calculated for each thickness tested on loaded and reference element and for each fire curve used, using:

$$k = \frac{t_l}{t_1 \times \frac{S_1}{S} \times \frac{D}{D_1}}$$

Where:

t_l	is the time for the loaded section to reach the design temperature.
t_1	is the time for the reference section to reach the design temperature.
S	is the section factor of the loaded section.
S_1	is the section factor of the reference section.
D	is the protection thickness for the loaded section.
D_1	is the protection thickness for the reference section.

Where the correction factor is greater than one, a correction factor of one is used.

The correction factors for all design temperatures above the temperature at which the loaded section fails loadbearing capacity as defined in EN 1363-1 is based on a lowest value derived as follows:
- determine the factor at a temperature equal to 100 °C below that at which loadbearing capacity failure occurred,
- determine factors for intermediate temperatures at intervals of 10 °C in the same way,
- select the lowest value and use for data correction for design temperatures above that at which loadbearing capacity failure occurred.

It is necessary to calculate all correction factors from 50 to 1200°C by step of 10°C for the next steps and especially the acceptability of the analysis as described in paragraph 13.5.3.

13.3.2. Correction of the data of the unloaded short profiles

The times for the short sections to reach the specified temperatures are corrected and the corrected times are used as input for the control of the acceptability of the analysis.

The worst-case correction factor k must be used for the correction of the data using the formula:

$$t_{exp,cor} = k_{worst} \times t_{exp}$$

Where:

$t_{exp,cor}$	is the corrected time to reach the design steel temperature.
k_{worst}	is the worst correction factor coming from all tests performed on furnace including with EN 1363-1 fire curve and “simulated natural fire curve” (real natural fire excluded at this stage).
t_{exp}	is the time to reach the design steel temperature from the test.

13.4. Variable thermal conductivity analysis

13.4.1. General

The variable thermal conductivity is based on the formula, which is described in annex E.3 of standard EN 13381-4 and paragraph 4.2.5.2 of standard EN 1993-1-2:

$$\Delta\theta_{a,t} = \left[\frac{\lambda_{p,t}/d_p}{c_a\,\rho_a} \times \frac{A_p}{V} \times \frac{1}{1+\emptyset/3} \times \left(\theta_t - \theta_{a,t}\right)\Delta t\right] - \left[e^{\emptyset/10} - 1\right]\Delta\theta_t \quad (1)$$

With

$$\emptyset = \frac{c_p\rho_p}{c_a\rho_a} \times d_p \times \frac{A_p}{V} \quad (2)$$

Where:

$\Delta\theta_{a,t}$	is the steel temperature rise over time step Δt, in degrees Kelvin;
$\Delta\theta_t$	is the furnace temperature rise over time step Δt, in degrees Kelvin;
d_p	is the thickness of protection product, in metres;
c_a	is the temperature dependant specific heat capacity of steel at θ_a, in joules per kilogram per kelvin;
ρ_a	is the density of steel, in kilograms per cubic metre;
c_p	is the temperature dependant specific heat capacity of the protection at θ_p, in joules per kilogram per kelvin. If not known, 1000 J/(kg.K) can be used.
ρ_p	is the density of the protection, in kilograms per cubic metre;
$A_{p/V}$	is the steel section factor based on actual dimensions of steel element, in m^{-1};
θ_t	is the furnace temperature in degrees Celsius;
$\theta a,t$	is the steel temperature, in degrees Celsius;
Δt	is the time step, in seconds;
$\lambda_{p,t}$	is the thermal conductivity of the protective material at time t and for d_p thickness of protective material, in watts per metre per degree Kelvin.

Concerning Δt:

- During a test, it shall not be higher than 10 seconds.
- For the analysis, the simulation of the steel temperature must be done using formula below with a maximum time step of 10 seconds

$$\Delta t = 0.8 \times \frac{c_a \times \rho_a}{\lambda_{p,t}/d_p} \times \frac{V}{A_p} \quad (3)$$

13.4.2. Step 1: Input data

To carry out the analysis properly, the following input data for all non-loaded short elements, tested with all fire curve, are necessary:

- the design temperatures which shall have at least three steps of 50°C.
- the average steel temperatures calculated in accordance with clause 3.1.12 of the standard EN 13381-4.
- the calculated section factor for the steel members.
- the thickness of the protection system.

13.4.3. Step 2: Preparation of input data

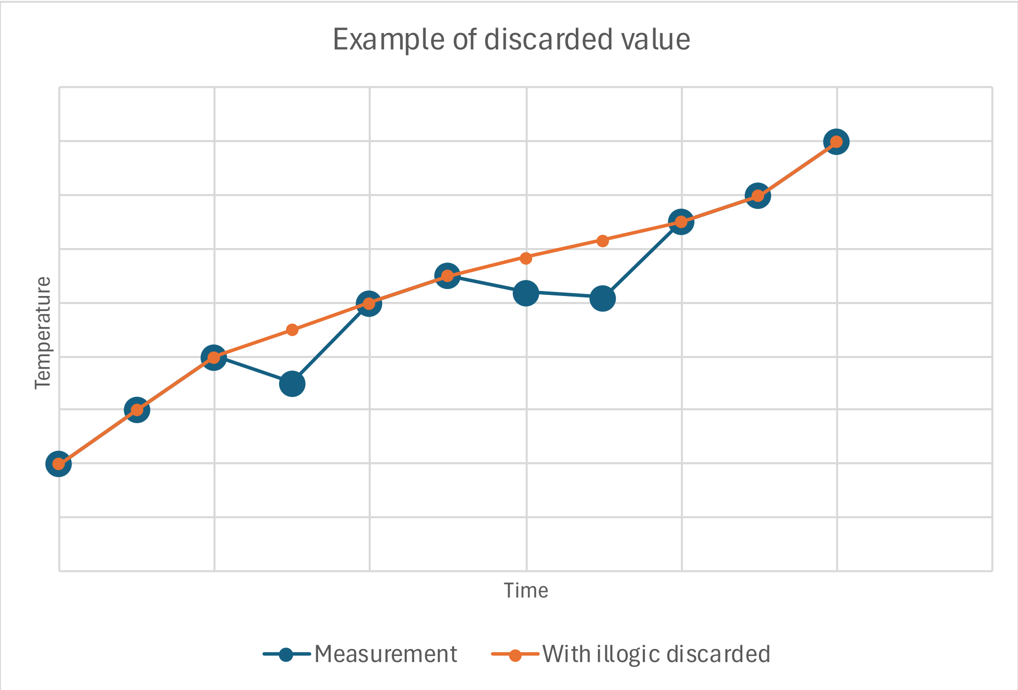
For various reasons, the temperature measurement between two measurement intervals can change illogically, for example the steel temperature decreases while the fire temperature increases, and vice versa.

Then, for each specimen, the average temperature between 2-time increments must be adjusted:

- For fire curve without cooling down phase: at any time, the steel temperature shall increase

- For fire curve with cooling down phase:
  - Define the maximum steel temperature reached,
  - Prior to that time, all temperatures should be only increasing,
  - After that time, all temperatures should be only decreasing.

Adjusting the illogic values means to replace them by new virtual values calculated using a linear interpolation.



13.4.4. Step 3: Determination of moisture plateau

Determine a smooth curve of moisture plateau length (D_p) versus fire protection material thickness (d_p) as in formula:

$$D_p = C \times {d_p}^3 \tag{4}$$

C can be found using all non-loaded short elements using the formula:

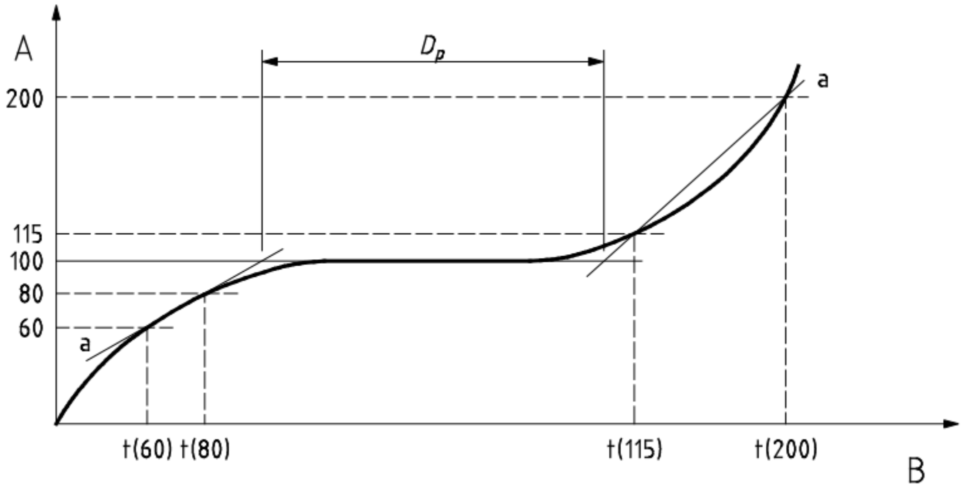
$$C = \frac{\sum_{i=1}^{n} {d_p}^3 \times D_p}{\sum_{i=1}^{n} {d_p}^6} \tag{5}$$

Where:

n	is the number of specimens.
D_p	is the moisture plateau length for each short section calculated as describe hereafter (minutes).
d_p	is the thickness of fire protection material on each short section (mm).

The moisture plateau length, D_p, is the distance between the intercept of the straight line (d1) and that of the similar straight line (d2) with the line θ = 100 °C, where:

- d1 is the straight line drawn through the following temperature/time points [60°C / t(60)min] and [80°C / t(80)min].
- d2 is the straight line drawn through the following temperature/time points [115°C / t(115)min] and [200°C / t(200)min].



13.4.5. Step 4: Determination of elementary variable conductivities from each short section

For each short section, basic formula (1) provides the thermal conductivity of the protective material versus time ($\lambda_{p,t}$):

$$\lambda_{p,t} = d_p \times \frac{1}{A_p/V} \times \left(1 + \frac{\emptyset}{3}\right) \times c_a \times \rho_a \times \frac{1}{(\theta_t - \theta_{a,t}) \times \Delta t} \times \left[\Delta\theta_{a,t} + \left(e^{\emptyset/10} - 1\right)\Delta\theta_t\right] \tag{6}$$

13.4.6. Step 5: Determination of the temperature of the protective system

For each short section and for each time interval, determine the protective material temperature versus time ($\theta_{p,t}$) using formula (7):

$$\theta_{p,t} = \frac{\frac{\theta_{t-1} - \theta_t}{2} + \frac{\theta_{a,t-1} - \theta_{a,t}}{2}}{2} \tag{7}$$

13.4.7. Step 6: Transformation of conductivities

As the thermal conductivity of the protective system versus time ($\lambda_{p,t}$) was defined in step 4 using formula (6), it is possible to transform it into thermal conductivity of the protection material versus the protective material temperature versus time calculated in step 5 with formula (7).

$$\lambda_{p,t} \Rightarrow \lambda_{p,\theta_p}$$

Example:

Time	Thermal conductivity
0	0.25
1	0.1988
2	0.0964
3	0.1427
4	0.1835

Thermal conductivity versus time

Time	Protection system temperature
0	20.37
1	177.98
2	228.74
3	260.75
4	289.35

Protective material temperature versus time

Thermal conductivity	Protection system temperature
0.25	20.37
0.1988	177.98
0.0964	228.74
0.1427	260.75
0.1835	289.35

Thermal conductivity versus protective material temperature

13.4.8. Step 7: Determination of average variable conductivities for the protective material

As the thermal conductivity may be dependent on the thickness of protective system, two thermal conductivities should be determined respectively for minimum and maximum thicknesses of protective material whatever the fire curve is.

- For the minimum thickness, the $\lambda_{min,\ mean,\ \theta p}$ relevant to short non-loaded sections protected with minimum thickness shall be considered for all fire curve,
- For the maximum thickness, the $\lambda_{max,\ mean,\ \theta p}$ relevant to short non-loaded sections protected with maximum thickness shall be considered for all fire curve.

For both the minimal and maximal thickness, the procedure is as follows for successive range [θ_p, θ_p + 50°C] for θ_p from 0 to 1 000 °C at 50 °C intervals, i.e. for 21 ranges.:

- from the elementary variable conductivities $\lambda_{p,\theta p}$, a mean variable conductivity of the protective material $\lambda_{mean,\theta p}$ shall be determined for each section protected with minimum thickness and sections protected with maximum thickness, from each elementary variable conductivity $\lambda_{p,\theta p}$, by calculating the arithmetical mean values $\lambda_{mean,\theta p}$.

Thermal conductivity	Protection system temperature
0.25	20.37
0.1988	177.98
0.0964	228.74
0.1427	260.75
0.1835	289.35

θ_p	
[0;50]	0.25
[50;100]	-
[100;150]	-
[150;200]	0.1988
[200;250]	0.0964
[250;300]	0.1631

- then for an average variable conductivity $\lambda_{avg,\theta p}$ and corresponding standard deviation shall be determined for each 50 °C temperature range. For both sets and for each range and from each arithmetical mean values of $\lambda_{mean,\theta p}$, calculate the arithmetical average values of $\lambda_{avg,\theta p}$ and the standard deviation $\sigma_{\theta p}$ associated.

Protection system temperature range	Thermal conductivities					
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	**Average**	**Deviation**
[0;50]	1,533	1,409	1,338	1,360	**1,410**	**0,087**
[50;100]	1,122	1,015	0,954	0,844	**0,984**	**0,116**
[100;150]	0,745	0,677	0,636	0,560	**0,654**	**0,078**
[150;200]	0,485	0,440	0,415	0,359	**0,425**	**0,053**
[200;250]	0,439	0,402	0,359	0,156	**0,339**	**0,126**
[250;300]	0,187	0,183	0,142	0,408	**0,230**	**0,120**
[300;350]	0,128	0,125	0,115	0,119	**0,122**	**0,006**
[350;400]	0,157	0,141	0,129	0,144	**0,143**	**0,012**
[400;450]	0,133	0,132	0,108	0,127	**0,125**	**0,012**
[450;500]	0,144	0,150	0,094	0,134	**0,130**	**0,025**
[500;550]	0,182	0,166	0,337	0,145	**0,208**	**0,088**
[550;600]	0,198	0,139	0,151	0,152	**0,160**	**0,026**
[600;650]	0,281	0,157	0,162		**0,200**	**0,070**
….						

NOTE:
Illogic values of $\lambda_{mean,\theta p}$ and then $\lambda_{avg,\theta p}$ can be obtained mainly for lower and higher temperature ranges. It could be then necessary to adapt manually some values (for example, using the λ at 20°C for lower temperature ranges and keep λ constant for higher temperature ranges using the last logic value).

13.4.9. Step 8: Simulation of the steel temperature

Using the thermal conductivities calculated previously, the temperature time curves for each tested section can be computed using the basic formula (1):

$$\Delta\theta_{a,t} = \left[\frac{\lambda_{p,t}/d_p}{c_a\,\rho_a} \times \frac{A_p}{V} \times \frac{1}{1+\emptyset/3} \times \left(\theta_t - \theta_{a,t}\right)\Delta t\right] - \left[e^{\emptyset/10} - 1\right]\Delta\theta_t$$

The value of $\lambda_{avg,\theta p}$ is related to dp and shall be calculated by linear interpolation between the $\lambda_{avg,\theta p}$ calculated for minimum and maximum thickness

For temperature θ_p higher than 1 000°C, use value of $\lambda_{avg,\theta p}$ determined for 20th range [950;1000]°C.

When the steel temperature reaches 100°C, the time to reach 100°C is increased by the length of the moisture plateau, D_p, calculated using formula (4), for the concerned thickness, and the processed continues.

13.5. Acceptability of the analysis

13.5.1. General

The acceptability of the analysis is carried out according to two methods:
- Acceptability criteria according to clause 13.5 of the standard EN 13381-4
- Deviation of the maximum temperature reached and its associated time

13.5.2. Step 9: Check on criteria of acceptability and adjustment of characteristic variable conductivities when necessary

From each recalculated steel temperature of non-loaded short element, determine times t_{recal} to reach the steel design temperatures.

For tests performed using a fire curve with a cooling down phase, determination of t_{recal} is carried out for the period when the steel temperatures increase.

Compare all the t_{recal} versus t_{exp}, with t_{exp} as the corrected times to reach the design temperatures.

The acceptability of the analysis within the range of steel section temperatures and duration of the test shall be judged up to the maximum temperature tested on the following basis:

a. For each short section, the predicted time in minutes to reach the design temperature calculated to one decimal place shall not exceed the corrected time by more than 15 %.
b. The mean value of all percentage differences as calculated in a) shall be less than zero.
c. A maximum of 30 % of individual values of all percentage differences as calculated in a) shall be more than zero.
d. The results of the analysis which satisfy a) to c) above shall also comply with the following rules provided all other parameters remain constant:
    1. The thickness of fire protection material increases with fire resistance time.
    2. As the section factor increases the fire resistance time decreases.
    3. As fire resistance time increases the temperature increases.
    4. As thickness increases temperature decreases.
    5. As section factor increases the temperature increases.
    6. As section factor increases thickness increases.

The criteria for acceptability shall be individually applied to all design temperatures included in the scope of the analysis.

Modification of the analysis should be made until the criteria of acceptability are met.

If the three criteria are satisfied, the average variable conductivities $\lambda_{avg,\theta p}$ for θ_p from 0 °C to 1 000°C at 50°C intervals and for minimum and maximum thicknesses respectively, can be estimated as representative of the performance of the protection product.

If not, the average variable conductivities $\lambda_{avg,\theta p}$ shall be modified in order that the acceptability criteria are satisfied.
To meet the acceptability criteria, the average conductivities $\lambda_{avg,\theta p}$ for minimum and maximum shall be modified by using:

$$\lambda_{char}(\theta_p) = \lambda_{ave}(\theta_p) + K \times \sigma(\theta_p) \quad (8)$$

The value of K shall be the lowest possible.
The same value shall be used for both minimum and maximum thicknesses of protective material.

The value of K may be found iteratively or, alternatively, by increasing the value in small steps.

Then, proceed again step 8 by using $\lambda_{char,\theta p}$ instead of $\lambda_{avg,\theta p}$ until the acceptability criteria are satisfied.
If not, increase K and repeat the process.

13.5.3. Step 10: Check on time to reach the maximum temperature

From each recalculated steel temperature of non-loaded short element tested fire a fire curve which includes a cooling down phase only, determine maximum temperature $T_{recal,max}$ and the times $t_{recal,max}$ to reach the maximum temperature.

Compare:
- All the $T_{recal,max}$ versus $T_{exp,max}$ with $T_{exp,max}$ as the maximum temperature reached
- all the $t_{recal,max}$ versus $t_{exp,max}$, with $t_{exp,max}$ as the corrected times to reach the maximum temperatures.

As the maximum temperature vary a lot depending on the steel profile, the fire curve, the correction factor can be estimated by interpolation.

Steel temperature	Correction factor
500°C	0.95
510°C	0.9

➔ Correction factor for 505°C= 0.925

The acceptability of the analysis shall be judged on the following basis and for both the maximum temperature and the time to reach the maximum temperature:
- Concerning the maximum temperature reached:

a. For each short section, the maximum temperature calculated shall not be lower than the maximum temperature from the test by less than 15 %.
b. The mean value of all percentage differences as calculated in a) shall be more than zero.
c. A maximum of 30 % of individual values of all percentage differences as calculated in a) shall be less than zero.

- Concerning the time to reach the maximum temperature:

a. For each short section, the predicted time in minutes to reach the maximum temperature calculated shall not exceed the corrected time by more than 15 %.
b. The mean value of all percentage differences as calculated in a) shall be less than zero.
c. A maximum of 30 % of individual values of all percentage differences as calculated in a) shall be more than zero.

Modification of the analysis should be made until the criteria of acceptability are met.
Modification is carried out as explained in paragraph 13.5.2.

14. CONFIRMATION OF THE ANALYSIS

14.1. General

The confirmation of the analysis consists of carrying out a test under natural fire using a different fire curve and a completely different set of steel profiles.

The experimental results of the natural fire test are compared to a numerical simulation using the properties obtained during the analysis made in paragraph 13.4 and 13.5.

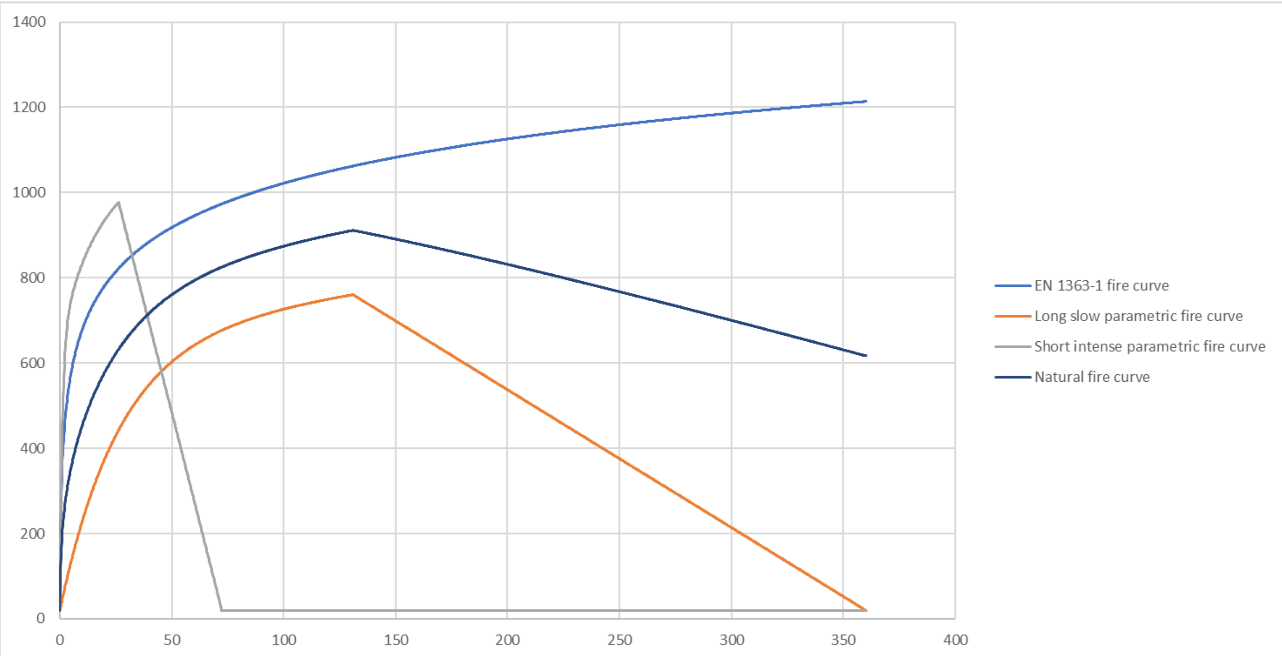
14.2. Test under natural (wood cribs) fire

14.2.1. General

The natural fire test must be performed in accordance with requirements of the paragraphs 4.2 and 5.4.

14.2.2. Fire

The natural fire curve that must be obtained shall be different from those used for the analysis and shall remain within their limits. The fire curves used on furnaces shall be used as limits during the real fire test in order to control the natural fire test is performed with a completely different fire curve.



Example of natural fire curve inside the scope of the curve used on furnace

The natural (wood cribs) fire curve describes in the graph is a pure example. The fire curve of the confirmation test will vary depending on the final scope to cover.

Quantity of timber cribs and their arrangement must be designed considering the dimensions of the testing chamber and the conditions of ventilation. In practice it will be difficult to accurately predict the fire load and ventilation conditions that will result in a certain natural fire curve. During the test, ventilation conditions may be adjusted. The actual fire curve in the test shall remain between the limits.

It is strongly recommended to perform calibration test(s) to adjust the timber cribs design as well as ventilation conditions if necessary.

14.2.3. Selection of the tested specimens

The selection of the steel sections must be done with a completely different set of profiles and protection thickness. The specimens selected shall not have been tested in furnaces.

The selection must include a loaded beam, a reference beam and at least 5 short columns.

The section of the loaded beam and its protection applied must be selected in such way the failure of the loadbearing capacity would be reached during the natural fire test. This selection means the steel temperature must be calculated using the thermal conductivities calculated and the target natural fire curve.

All other conditions of the test must be done:
- According to paragraphs 5.2 and 5.3 concerning the load applied,
- According to paragraph 7 concerning installation of the test specimens inside the test chamber,
- According to paragraph 8 concerning the conditioning,
- According to paragraph 9 concerning the instrumentation, with addition of some sheathed thermocouples (minimum 4) type K with a diameter of 1.5 mm, placed near the plate thermometers. They can be useful to anticipate the behaviour of the natural fire and to help the monitoring of the curve through the ventilation conditions. Each steel section shall have at least two plate thermometers in its neighbouring,
- According to paragraph 10 concerning the test procedure with scan intervals that shall not exceed 1 seconds, at least for the measurements of the fire.

The natural fire curve obtained might be slightly different from the target curve due to the influence of certain parameters that are difficult to fully control.
It is allowed to deviate from the expected curve as long as the fire curve obtained remains different from the fire curves used on furnace and comprised within furnace curves limits.

14.3. Final comparison

14.3.1. Correction factor comparison

The correction factor coming from the loaded beam and its reference beam tested under natural fire must be compared with the correction factor used in the previous analysis and must be higher.

If this correction factor is less, then it has to be used as new lowest correction factor and the analysis must be repeated.

14.3.2. Thermal transfer comparison

By using the formula (1), the thermal conductivities calculated in paragraphs 13.4 and 13.5, and the real natural fire curve obtained, the temperature curves for each tested under natural fire section can be computed.
It should be done as described in paragraph 13.4.9.

The comparison must be done using the same acceptability criteria as defined in paragraphs 13.5.2 and 13.5.3.

Note:
The thermal transfer comparison must be done first using the mean temperature of the fire, but, when the fire temperature is different depending on the location, it might be necessary to use the plate thermometers next to a specific specimen for its analysis.

15.FIELD OF APPLICATION OF THE ANALYSIS

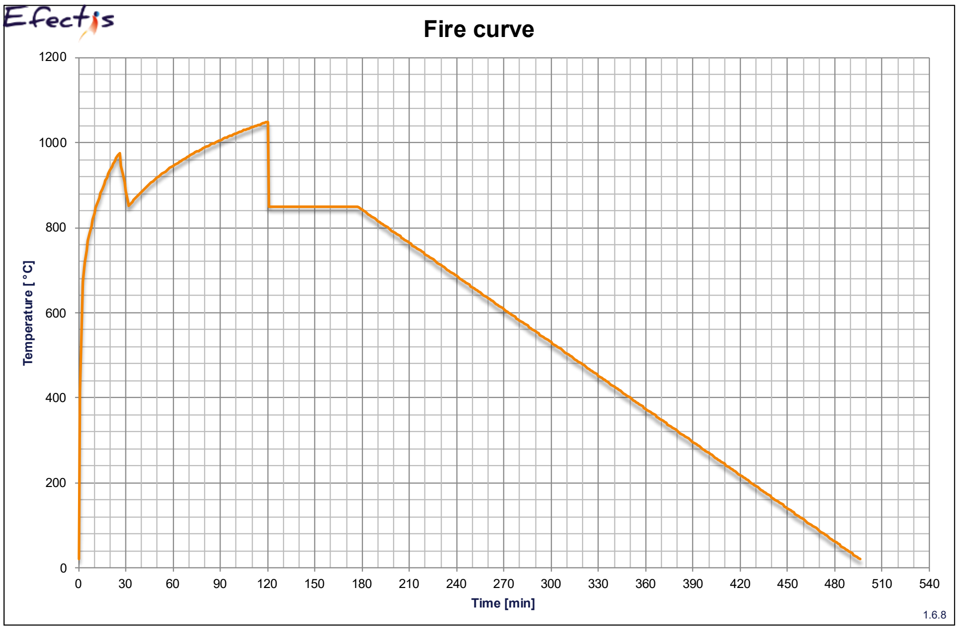
15.1. General

Unlike existing methods dealing with elements subjected to real fire, such as ISO 18195 which aims to define the scope of application of the natural fire performance of a construction product in a Nuclear Plant configuration, this guide aims to define the scope of application of the necessary characteristics for the calculations of the fire stability of protected steel member subjected to natural fire.

15.2. Limitation on fire scenario

The characteristics for the calculations of the fire stability of protected steel member subjected to natural fire are applicable to any fire scenario which remains under the combination of all fire temperature used in the analysis.

An example of limitation could be:



15.3. Limitation of fire duration

15.3.1. Standard fire curve

When the limited fire scenario is defined, even partially, by the standard fire curve EN 1363-1, the maximum duration under the standard fire curve is given by the loaded sections protected with the maximum protection thickness which shall achieve a load bearing capacity performance within 85 % of this period.

15.3.2. Parametric fire curve

The limitation is given when the fire temperature returns to the ambient temperature.

15.4. Limitation from standard EN 13381-4

All other limitation mentioned in standard EN 13381-4 are applicable.
This concerns, but is not exhaustive:

- Orientation of the steel members
- The steel grade
- The dimensions of the steel members: maximum web depth and section factors
- The permitted protection thickness
- The applicability to section other than I or H sections.