Brandteknisk provning av byggnadsdelar –
Bidrag till brandmotstånd –
Del 4: Skydd av stålkonstruktioner

Test methods for determining the contribution
to the fire resistance of structural members –
Part 4: Applied protection to steel members


Dokumentet består av 78 sidor.

Upplysningar om sakinnehållet i standarden lämnas av SIS, Swedish Standards Institute, tel 08 - 555 520 00.

Standarder kan beställas hos SIS Förlag AB som även lämnar allmänna upplysningar om svensk och utländsk standard. 
Postadress: SIS Förlag AB, 118 80 STOCKHOLM 
Telefon: 08 - 555 523 10. Telefax: 08 - 555 523 11 
E-post: sis.sales@sis.se. Internet: www.sis.se
Test methods for determining the contribution to the fire resistance of structural members - Part 4: Applied protection to steel members
Contents

Foreword ....................................................................................................................... ........................................3
1 Scope ......................................................................................................................... ...................................4
2 Normative references.......................................................................................................... ..........................5
3 Terms and definitions, symbols and units...................................................................................... ...............5
4 Test equipment ................................................................................................................ .............................8
5 Test conditions............................................................................................................... ...............................8
6 Test specimens................................................................................................................ ............................10
7 Installation of the test specimens ............................................................................................ ....................15
8 Conditioning of the test specimens ............................................................................................ .................16
9 Application of instrumentation ............................................................................................ ..........................16
10 Test procedure ............................................................................................................... .............................18
11 Test results................................................................................................................. .................................20
12 Test report.................................................................................................................. .................................21
13 Assessment ................................................................................................................... ..............................22
14 Report of the assessment..................................................................................................... ........................29
15 Limits of the applicability of the results of the assessment ................................................................. ........30
Annex A (normative)  Test method to the smouldering fire or slow heating curve.............................................53
Annex B (normative)  The applicability of the results of the assessment to sections other than ‘I’ or ‘H’ section .................................................................................................................................................................56
Annex C (normative)  Measurement of properties of fire protection materials ...................................................58
Annex D (normative)  Fixing of thermocouples to steel work and routing of cables ..........................................61
Annex E (normative)  Correction for discrepancies in thickness between loaded and equivalent unloaded sections ........................................................................................................................................................................63
Annex F (normative)  Assessment methodology: Differential equation analysis (variable \( \lambda \) approach) .............64
Annex G (normative)  Assessment methodology: Differential equation analysis (constant \( \lambda \) approach) .............70
Annex H (normative)  Assessment methodology: Numerical regression analysis ...............................................72
Annex J (normative)  Assessment methodology: Graphical presentation ............................................................74
Bibliography................................................................................................................... .....................................76
Foreword

This document ENV 13381-4:2002 has been prepared by Technical Committee CEN/TC127 "Fire safety in buildings", the secretariat of which is held by BSI.

This document has been prepared under the mandate given to CEN/TC127 by the Commission and the European Free Trade Association.

As there was little experience in carrying out these tests in Europe CEN/TC127 agreed that more experience should be built up during a prestandardization period before agreeing text as European Standards. Consequently all parts are being prepared as European Prestandards.

This European Prestandard is one of a series of standards for evaluating the contribution to the fire resistance of structural members by applied fire protection materials. Other parts of this ENV are:

Part 1: Horizontal protective membranes.
Part 2: Vertical protective membranes.
Part 3: Applied protection to concrete members.
Part 5: Applied protection to concrete/profiled sheet steel composite members.
Part 7: Applied protection to timber members.

Annexes A to J are normative.

Caution

The attention of all persons concerned with managing and carrying out this fire resistance test, is drawn to the fact that fire testing can be hazardous and that there is a possibility that toxic and / or harmful smoke and gases can be evolved during the test. Mechanical and operational hazards can also arise during the construction of test elements or structures, their testing and the disposal of test residues.

An assessment of all potential hazards and risks to health should be made and safety precautions should be identified and provided. Written safety instructions should be issued. Appropriate training should be given to relevant personnel. Laboratory personnel should ensure that they follow written safety instructions at all times.

The specific health and safety instructions contained within this prestandard should be followed.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to announce this European Prestandard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.
1 Scope

This part of this European Prestandard specifies a test method for determining the contribution made by applied fire protection systems to the fire resistance of structural steel members, which can be used as beams, columns or tension members.

The evaluation is designed to cover a range of thicknesses of the applied fire protection material, a range of steel sections, characterized by their section factors, a range of design temperatures and a range of valid fire protection classification periods.

This European Prestandard applies to fire protection materials where the gap between the material and the flange faces of the steel member is less than 5 mm in size. Otherwise, the test methods in ENV 13381-1 or ENV 13381-2, as appropriate, apply.

This European Prestandard contains the fire test which specifies the tests which should be carried out to determine the ability of the fire protection system to remain coherent and fixed to the steelwork, and to provide data on the thermal characteristics of the fire protection system, when exposed to the standard temperature/time curve specified in EN 1363-1.

In special circumstances, where specified in national building regulations, there can be a need to subject reactive protection material to a smouldering curve. The test for this and the special circumstances for its use are described in annex A.

The fire test methodology makes provision for the collection and presentation of data which can be used as direct input to the calculation of fire resistance of steel structural members in accordance with the procedures given in ENV 1993-1-2.

This European Prestandard also contains the assessment which prescribes how the analysis of the test data should be made and gives guidance on the procedures by which interpolation should be undertaken.

The assessment procedure is used to establish:

a) on the basis of temperature data derived from testing loaded and unloaded sections, a correction factor and any practical constraints on the use of the fire protection system under fire test conditions, (the physical performance);

b) on the basis of the temperature data derived from testing short steel column sections, the thermal properties of the fire protection system, (the thermal performance).

The limits of applicability of the results of the assessment arising from the fire test are defined, together with permitted direct application of the results to different steel sections and grades and to different fire protection systems and fixings.

The results of the test and assessment obtained according to this part of ENV 13381 are directly applicable to steel sections of "I" and "H" cross sectional shape. Guidance is given in annex B on the application of the data obtained from "I" and "H" steel sections to other section shapes.
2 Normative references

This European Prestandard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Prestandard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 1363-1 Fire resistance tests - Part 1: General requirements.
EN 1363-2 Fire resistance tests - Part 2: Alternative and additional procedures.
EN 10025 Hot rolled products of non-alloy structural steels - Technical delivery conditions.
EN 10113 Hot rolled products in weldable fine grade structural steels.

3 Terms and definitions, symbols and units

3.1 Terms and definitions

For the purposes of this European Prestandard, the terms and definitions given in EN 1363-1, EN ISO 13943 and ISO 8421-2, together with the following, apply:

3.1.1 steel member
element of building construction which is loadbearing and fabricated from steel

3.1.2 fire protection material
material or combination of materials applied to the surface of a steel member for the purpose of increasing its fire resistance

3.1.3 passive fire protection materials
materials which do not change their physical form on heating, providing fire protection by virtue of their physical or thermal properties. They may include materials containing water which, on heating, evaporates to produce cooling effects

3.1.4 reactive fire protection materials
materials which are specifically formulated to provide a chemical reaction upon heating such that their physical form changes and in so doing provide fire protection by thermal insulative and cooling effects

3.1.5 fire protection system
fire protection material together with a prescribed method of attachment to the steel member
3.1.6 fire protection
definition:

Protection afforded to the steel member by the fire protection system such that the temperature of the steel member is limited throughout the period of exposure to fire.

3.1.7 test specimen
definition:

Steel test section plus the fire protection system under test. The steel test section, representative of a steel member, for the purposes of this test, comprises short steel columns, tall columns or beams.

3.1.8 fire protection thickness
definition:

Thickness of a single layer fire protection system or the combined thickness of all layers of a multilayer fire protection system.

3.1.9 stickability
definition:

Ability of a fire protection material to remain sufficiently coherent and in position for a well defined range of deformations, furnace and steel temperatures, such that its ability to provide fire protection is not significantly impaired.

3.1.10 section factor
definition:

- **profiled**
  
  Ratio of the fire exposed outer perimeter area of the steel structural member itself, per unit length, to its cross sectional volume per unit length, see Figure 1.

- **boxed**
  
  Ratio of the sum of the inside dimensions of the smallest possible rectangle or square encasement which can be measured around the steel structural member times unit length, to its volume per unit length, see Figure 1.

3.1.11 design temperature
definition:

Temperature of a steel structural member for structural design purposes.

3.1.12 characteristic steel temperature
definition:

Temperature of the steel structural member which is used for the determination of the correction factor for stickability.

3.2 Symbols and units

table:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB</td>
<td></td>
<td>loaded beam section</td>
</tr>
<tr>
<td>UB</td>
<td></td>
<td>unloaded beam section</td>
</tr>
<tr>
<td>LC</td>
<td></td>
<td>loaded 3 metre column section</td>
</tr>
<tr>
<td>TC</td>
<td></td>
<td>unloaded Tall (2 metre) column section</td>
</tr>
<tr>
<td>SC</td>
<td></td>
<td>short column section</td>
</tr>
<tr>
<td>p</td>
<td>m</td>
<td>fire protection material</td>
</tr>
<tr>
<td>a</td>
<td></td>
<td>steel</td>
</tr>
<tr>
<td>f</td>
<td></td>
<td>furnace</td>
</tr>
<tr>
<td>d</td>
<td>m</td>
<td>thickness</td>
</tr>
<tr>
<td>$\rho$</td>
<td></td>
<td>density</td>
</tr>
<tr>
<td>$A_p/V$</td>
<td>m$^{-1}$</td>
<td>section factor of the unprotected steel section</td>
</tr>
<tr>
<td>$A_p/V$</td>
<td>m$^{-1}$</td>
<td>section factor of the protected steel section</td>
</tr>
<tr>
<td>$A_p$</td>
<td>m$^2$/m</td>
<td>area of the protected steel section, around the profile (profiled) or over the linear</td>
</tr>
</tbody>
</table>
### Dimensions and Material Specifications

- **$A$** $m^2$: Cross sectional area of the steel section
- **$V$** $m^3/m$: Volume of the steel section per unit length
- **$V_p$** $m^3/m$: Volume of the fire protection material per unit length
- **$h$** mm: Depth of the steel section
- **$b$** mm: Flange breadth of the steel section
- **$t_w$** mm: Thickness of the web of the steel section
- **$L_{exp}$** mm: Length of beam specimen exposed to heating
- **$L_{sup}$** mm: Length of beam specimen between supports
- **$d_{UB}$** mm: Thickness of fire protection material on an unloaded beam section
- **$d_{SC}$** mm: Thickness of fire protection material on an unloaded column section
- **$d_p$** mm: Thickness of fire protection material concerned
- **$d_{(max)}$** mm: Maximum thickness of fire protection material used
- **$d_{(min)}$** mm: Minimum thickness of fire protection material used
- **$\rho_{protection}$** $kg/m^3$: Density of fire protection material
- **$\rho_{UB}$** $kg/m^3$: Density of fire protection material on an unloaded beam section
- **$\rho_{SC}$** $kg/m^3$: Density of fire protection material on an unloaded column section
- **$\rho_{LB}$** $kg/m^3$: Density of fire protection material on a loaded beam
- **$\rho_s$** $kg/m^3$: Density of steel (normally 7850 $kg/m^3$)
- **$\theta_{SC}$** °C: Mean (or characteristic) steel temperature of a short column (see 13.2.2)
- **$\theta_{LB}$** °C: Characteristic steel temperature of a loaded beam
- **$\theta_{UB}$** °C: Characteristic steel temperature of an unloaded beam
- **$\theta_{LC}$** °C: Characteristic steel temperature of a loaded column
- **$\theta_{TC}$** °C: Characteristic steel temperature of a tall column
- **$\theta_{(UB)}$** °C: Corrected temperature of an unloaded beam section
- **$\theta_t$** °C: Average temperature of the furnace at time $t$
- **$\theta_d$** °C: Average temperature of the steel at time $t$
- **$\Delta \theta_t$** °C: Increase of furnace temperature during the time interval $\Delta t$
- **$\theta_{m(SC)}$** °C: Modified steel temperature of an unloaded column section
- **$\theta_D$** °C: Design temperature
- **$k(\theta)$**: Correction factor for temperature of an unloaded section at a temperature $\theta$
- **$k(\theta_{LB})_{(max)}$**: Correction factor for temperature based on beams for a short section at a temperature $\theta$ with maximum thickness of applied fire protection material
- **$k(\theta_{LB})_{(min)}$**: Correction factor for temperature based on beams for a short section at a temperature $\theta$ with minimum thickness of applied fire protection material
- **$k(\theta)_C$**: Correction factor for temperature based on columns for a short section at a temperature $\theta$ with maximum thickness of applied fire protection material
- **$k_d(\theta)$**: Correction factor for temperature of a short column section at a thickness of fire protection material $d$ and at a temperature $\theta$
- **$k_d(\theta_{LB})$**: Correction factor for temperature based on beams for a short section at a thickness of fire protection material $d$ and at a temperature $\theta$
- **$k_d(\theta_{TC})$**: Correction factor for temperature based on tall columns (or loaded columns) for a short section at a thickness of fire protection material $d$ and at a temperature $\theta$
- **$k_{max}(\theta)$**: Correction factor for temperature of a short section at maximum thickness of fire protection material $d_{max}$
\[ k_{\text{min}}(\theta) \]

correction factor for temperature of a short section at minimum thickness of fire protection material \(d_{\text{min}}\)

\[ C_a \quad \text{J/kg °C} \]

temperature dependant specific heat of steel as defined in ENV 1993-1-2

\[ C_p \quad \text{J/kg °C} \]

temperature independant specific heat of the fire protection material

\[ \mu \]

ratio of heat capacity of the fire protection material to that of the steel section

\[ t \quad \text{min} \]

time from commencement of the start of the test

\[ t_e \quad \text{min} \]

time for an unloaded section to reach an equivalent temperature to the loaded beam at time \(t\)

\[ \Delta t \quad \text{min} \]

time interval

\[ t_D \quad \text{min} \]

time required for a short steel column section to reach the design temperature

\[ \lambda_p \quad \text{W/m °C} \]

effective thermal conductivity of the fire protection material

\[ \lambda_{\text{char}(p)} \quad \text{W/m °C} \]

characteristic value of effective conductivity of the fire protection material

\[ \lambda_{\text{ave}(p)} \quad \text{W/m °C} \]

mean value of \(\lambda_p\) calculated from all the short column sections at a temperature \(\theta_{SC}\)

\[ \lambda_{\text{std}(p)} \quad \text{W/m °C} \]

standard deviation of \(\lambda_p\) calculated from all the short column sections at a temperature \(\theta_{SC}\)

\[ C_{\text{in}(\theta)} \]

constant derived for short section at temperature \(\theta\)

\[ K \]

constant applied to \(\lambda_{\text{std}(p)}\)

## 4 Test equipment

### 4.1 General

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

### 4.2 Furnace

The furnace shall be designed to permit the dimensions of the test specimens to be exposed to heating, be they short columns, tall columns or beams, to be as specified in 6.2 and their installation upon or within the test furnace to be as specified in clause 7.

### 4.3 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 and to columns as specified in 5.2.3.

## 5 Test conditions

### 5.1 General

A number of short steel, "I" or "H" test sections, protected by the fire protection system, is heated in a furnace according to the protocol given in Figures 2, 3 and 4.

Loaded and unloaded beams or columns (see Table 1) that are likewise heated provide information on the ability of the fire protection system to remain intact and adhere to the steel test sections (stickability).

The method of testing loaded beams in this part of the test method is designed to provide maximum deflection under the influence of load and heating.

It is recommended that the tests be continued until the steel temperature reaches the maximum value commensurate with application of the data, usually 750 °C.
Where several test specimens are tested simultaneously, care shall be taken that each 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.

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 simply supported span shall be not greater than the length exposed to heating by more than 250 mm at each end.

Loading shall be uniformly and symmetrically applied at two or more locations along its length. Point loads shall be applied directly via loading spacers introduced through the cover slabs, see Figure 5. These spacers may be of any suitable material but if they are of steel or other high conductivity material, unless the contact surface at each loading point is less than or equal to 100 mm × 100 mm or 10 000 mm², they shall be insulated from the steel beam by a suitable insulation material.

5.2.2 Unloaded beams

Each unloaded beam test specimen shall be supported as shown in Figure 6.

5.2.3 Loaded columns

For each loaded column provision shall be made for the proper support, positioning and alignment of the column test specimen in the furnace and for ensuring uniform distribution of the loading over the ends of the specimen, see Figure 7.

The ends of the specimen shall be designed and detailed for the proper transmission of the test load from the loading platens to the specimen. The loadbearing faces at top and bottom of the column shall be parallel to each other and perpendicular to the axis of the column to avoid introduction of bending moments.

For protection of the loading equipment against heat, provision shall be made for the attachment of collars at each end of the test specimen. These shall be designed to locate the column and to provide an adequate seal with the furnace walls and shall be suitably attached and supported so that they remain effective and in position throughout the heating period.

The method adopted to provide the seal shall allow the test specimen to move within the furnace walls without significantly affecting the load transmitted from the loading rig to the specimen or the fixity at the ends of the specimen.

5.2.4 Unloaded columns

A tall column test specimen or short column section test specimens shall be supported vertically within the furnace, either installed to the soffit of the furnace cover slabs, (see Figure 8), or stood, directly or on plinths, on the furnace floor.

5.3 Loading

The loaded beam test specimens shall be subjected to a total load which represents 60 % of the design moment resistance, according to ENV 1993-1-1, calculated using the nominal steel strength and the recommended boxed values given in ENV 1993-1-1.

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