TECHNICAL REPORT

ISO/TR 13387-6

First edition
1999-10-15

Fire safety engineering —

Part 6:
Structural response and fire spread beyond the enclosure of origin

Ingénierie de la sécurité contre l'incendie —

Partie 6: Réponse structurelle et propagation du feu au-delà de l'enceinte d'origine

Reference number
ISO/TR 13387-6:1999(E)

Contents

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Printed in Switzerland

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of ISO technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13387-6, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

It is one of eight parts which outlines important aspects which need to be considered in making a fundamental approach to the provision of fire safety in buildings. The approach ignores any constraints which might apply as a consequence of regulations or codes; following the approach will not, therefore, necessarily mean compliance with national regulations.

ISO/TR 13387 consists of the following parts, under the general title *Fire safety engineering*:

— *Part 1: Application of fire performance concepts to design objectives*

— *Part 2: Design fire scenarios and design fires*

— *Part 3: Assessment and verification of mathematical fire models*

— *Part 4: Initiation and development of fire and generation of fire effluents*

— *Part 5: Movement of fire effluents*

— *Part 6: Structural response and fire spread beyond the enclosure of origin*

— *Part 7: Detection, activation and suppression*

— *Part 8: Life safety — Occupant behaviour, location and condition*

Introduction

An important feature of design for fire safety, whether it is undertaken employing prescriptive regulations or fire safety engineering principles, is to ensure that building elements prevent (or delay) the spread of fire and prevent (or delay) structural failure. Measures must be taken to ensure the spread of fire and structural failure do not threaten the lives of occupants and firefighters, or compromise other fire safety objectives.

In prescriptive fire safety design, extensive use is made of the fire resistance of building elements as determined by the standard fire resistance test ISO 834-1. Inherent in this test are criteria concerned with load-bearing capacity, integrity and thermal insulation. Fire resistance requirements may be prescribed in national regulations and codes according to the use of the building, the size of fire compartments and the height of the building.

Design may also be undertaken employing fire safety engineering principles in which neither the temperature-time curve nor the duration of the exposing fire are prescribed. Instead, pertinent characteristics of the exposing fire are calculated to be representative of one (or several) fire scenarios envisioned for the building. The thermal and mechanical response of building elements subjected to such exposing fires are then calculated. Finally, the performance of building elements (specifically their ability to inhibit fire spread and structural failure) are assessed using criteria which, depending on the conditions at hand, may differ from the fire resistance criteria within ISO 834-1.

This part of ISO/TR 13387 is intended for use together with the other Technical Reports as described in clause 5. For some applications however this document alone may be sufficient.

Clause 6 describes and provides guidance on the approaches available to characterize the physical and chemical processes which govern the thermal and mechanical responses of building elements exposed to fire.

Clause 7 is a discussion of engineering methods to predict the thermal and mechanical response of building elements exposed to fire and thereby to evaluate the potential for fire spread and structural failure. It should be noted that whatever method is selected, it should be assessed and verified using the principles documented in ISO/TR 13387-3. Furthermore, special care should be taken when using input data published in the literature. The quantitative information may be related to specific test conditions and/or specific commercial products, and the application of the data under different conditions may result in significant errors.

Finally, in clause 8, guidance on interpreting the results of an analysis of the potential of structural failure and fire spread is provided. This includes guidance on the selection of criteria for assessing the effectiveness of fire safety measures meant to reduce the potential of structural failure or fire spread. The latter is only possible if the objectives of fire safety design have been clearly specified.

Fire safety engineering —

Part 6:
Structural response and fire spread beyond the enclosure of origin

1 Scope

This part of ISO/TR 13387 is intended to provide general guidance on the use of engineering methods for the prediction of fire spread within and between buildings, and for the prediction of the response of a structure exposed to fire. The report is not intended as a detailed technical design guide, but could be used as the basis for development of such a guide.

This part of ISO/TR 13387 provides a framework for critically reviewing the suitability of an engineering method for assessing the potential for fire spread and for fire damage to a building's structure. It also provides guidance for assessing the effectiveness of fire safety measures meant to reduce these potentials.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 13387. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TR 13387 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 834-1:1999, *Fire-resistance tests — Elements of building construction — Part 1: General requirements.*

ISO 7345:1987, *Thermal insulation — Physical quantities and definitions*.

ISO/TR 10158:1991, *Principles and rationale underlying calculation methods in relation to fire resistance of structural elements.*

ISO/TR 12470:1998, *Fire resistance tests — Guidance on the application and extension of results*.

ISO/TR 13387-1, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives.*

ISO/TR 13387-2, *Fire safety engineering — Part 2: Design fire scenarios and design fires.*

ISO/TR 13387-3, *Fire safety engineering — Part 3: Assessment and verification of mathematical fire models.*

ISO/TR 13387-4, *Fire safety engineering — Part 4: Initiation and development of fire and generation of fire effluents.*

ISO/TR 13387-5, *Fire safety engineering — Part 5: Movement of fire effluents.*

ISO/TR 13387-7, *Fire safety engineering — Part 7: Detection, activation and suppression.*

ISO/TR 13387-8, *Fire safety engineering — Part 8: Life safety — Occupant behaviour, location and condition.*

ISO 13943, *Fire safety — Vocabulary.*

3 Terms and definitions

For the purposes of this part of ISO/TR 13387, the definitions given in ISO 13943, ISO/TR 13387-1 and the following apply.

3.1
building element
integral component of the structure or fabric of a building, including floors, walls, beams, columns, doors, etc. complete with penetrations, but does not include building contents

3.2
enclosure
space defined by boundary elements

3.3
integrity
ability of a separating element, when exposed to fire on one side, to prevent the passage of flames and hot gases or the occurrence of flames on the unexposed side

3.4
load-bearing capacity
ability of a building element (or structure) to sustain applied actions (loads) when exposed to fire

3.5
mechanical response
measure of fire induced changes to the deflection, stiffness and load-bearing capacity of building elements and the development of openings (cracks) in building elements during fire exposure as a result of the shrinkage (expansion) of materials, spalling, delamination, etc.

3.6
thermal diffusivity
thermal conductivity divided by the density and specific heat, expressed in $m^2 \cdot s^{-1}$, given by $\kappa = k/(\rho \cdot c)$

3.7
thermal inertia
product of thermal conductivity, density and specific heat (square of thermal effusivity according to ISO 7345), given by $k \cdot \rho \cdot c$,

It is expressed in $J^2 \cdot m^{-4} \cdot K^{-2} \cdot s^{-1}$.

3.8
thermal insulation
the ability of a separating element, when exposed to fire on one side, to prevent the transmission of excessive heat

3.9
thermal response
a measure of:

a) fire induced changes to the temperature profile within building elements; and

b) the development of openings in building elements during fire exposure as a result of the melting of materials

4 Symbols and abbreviated terms

c specific heat of a material, expressed in $J \cdot kg^{-1} \cdot K^{-1}$

k thermal conductivity, expressed in $W \cdot m^{-1} \cdot K^{-1}$

κ thermal diffusivity, expressed in $m^2 \cdot s^{-1}$

ρ density, expressed in $kg \cdot m^{-3}$

5 Subsystem 3 of the total design system

The approach adopted in this part of ISO/TR 13387 is to acknowledge that assessment of structural response and fire spread addresses only a subsection of the global objectives of fire safety design. Global design, described in more detail in the framework document, ISO/TR 13387-1, is divided into subsystems. The key principles of the global design approach are that interdependencies among the subsystems are evaluated and that pertinent considerations for each subsystem are identified. Structural response and fire spread is subsystem 3 (SS3) of the total fire safety design system.

In the framework document, global fire safety design is illustrated by an information bus analogy. The information bus has three layers: global information, evaluations and process buses. The global information includes data which are either transferred among subsystems or employed to make engineering decisions. SS3 links with the global information are shown in Figure 1. The second layer of the bus system depicts the evaluations which must be undertaken within SS3 to evaluate structural response and fire spread. The third layer elucidates the fundamental processes which come into play in each evaluation undertaken within SS3.

SS3 draws on other subsystems for certain input data and generates output data which are used by yet other subsystems. For example, SS1 provides predictions of the temperature and heat flux history (thermal profile) in the enclosure of concern. These data along with the description of building assemblies (building parameters) are employed by SS3 to predict the likelihood (and time) of fire spread, and the likelihood (and time) of structural failure. Once a prediction has been made “output” data describing the building condition are placed on the global information bus. Building condition data may subsequently become “input” data for evaluations undertaken by SS1 and SS2 to calculate, for example, the potential for fire spread (and the subsequent fire size).

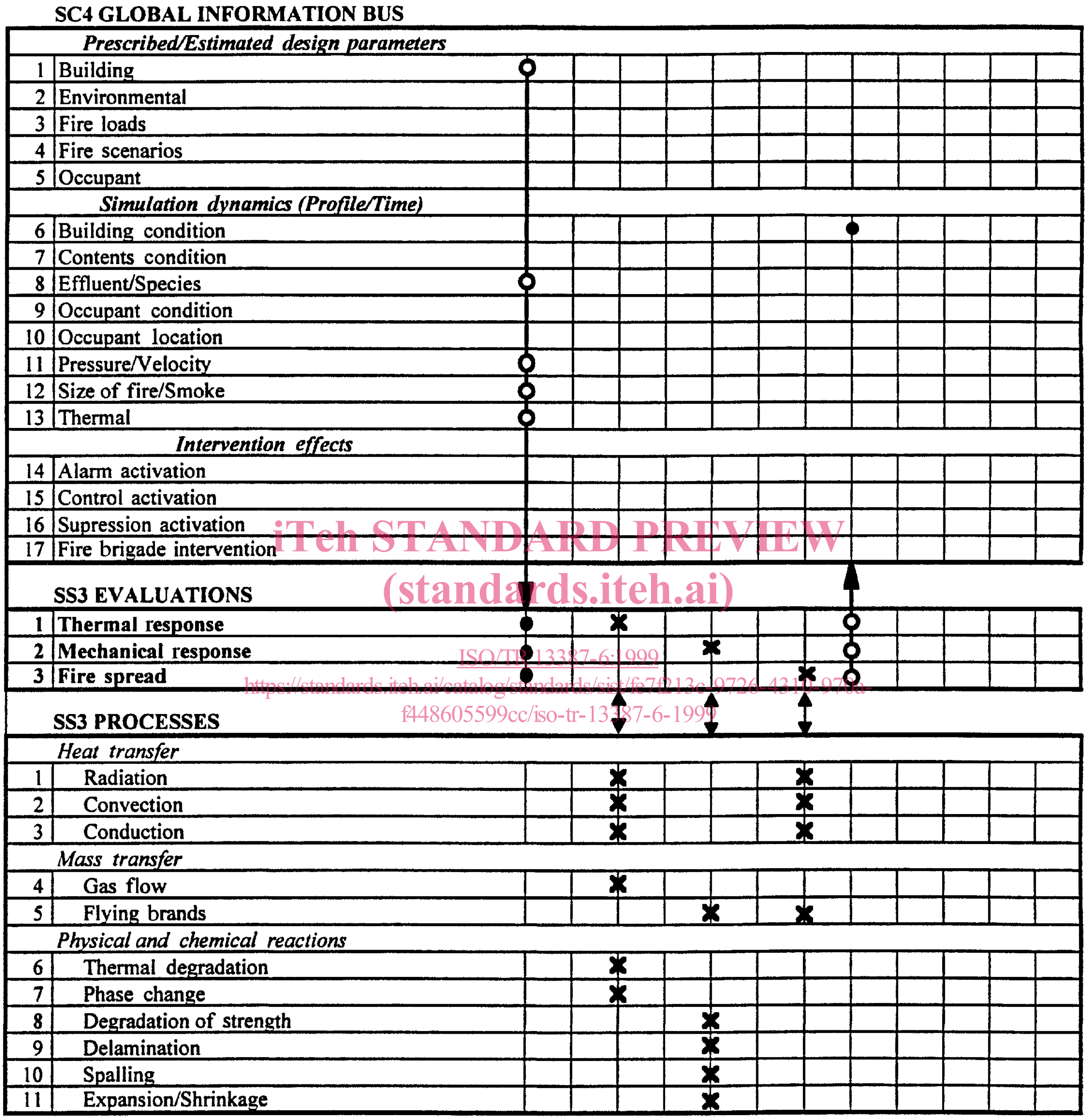
The transfer of data between the global information bus and the evaluations undertaken in SS3 is depicted explicitly in Figure 1. As Figure 1 indicates it is necessary to calculate (evaluate) the thermal response and mechanical response of building systems and then determine whether fire spread will occur. Guidance on undertaking such calculations is given in clause 6.

The fundamental processes which come into play in these evaluations are also depicted in Figure 1. An engineering analysis will incorporate these fundamental processes to an appropriate level of rigour as discussed in clause 6.

It should be noted that Figure 1 has been constructed to elucidate the process involved in undertaking an evaluation of the potential for structural failure or fire spread. It is not intended to include all possible phenomena.

ISO TC 92/SC 4 FIRE SAFETY ENGINEERING BUS SYSTEM

Subsystem 3 (SS3) — Structural response and fire spread beyond the enclosure of origin



Bus connection key
● = Input data
O = Output data
✖ = Subsystem buses data exchange

Figure 1 — Illustration of the global information, evaluation and process buses for SS3

6 Subsystem 3 evaluations

6.1 General

In this clause, guidance on predicting and evaluating the thermal and mechanical response of building elements and structures exposed to fire are discussed. Guidance on assessing whether fire spread will occur is also provided. The input data required to undertaken such evaluations and the possible output information are identified. Where possible, reference is made to literature which provides a more detailed discussion of the material presented in this clause.

6.2 Thermal response

6.2.1 Role in fire safety engineering design

This clause provides an overview of the assessment of the thermal response of building elements which are in one way or other exposed to heating from fire. The exposing fire may be a localized fire within an enclosure, a post-flashover enclosure fire, or perhaps an external fire. The nature of the exposing fire will have already been derived by SS1 or possibly specified as a design fire by ISO/TR 13387-2.

An accurate prediction of the thermal response of building elements exposed to fire is essential in fire safety engineering design. In the first instance, it allows for an assessment of the degree of thermal damage that may be sustained by building elements exposed to fire. This may be particularly important if a building is to be designed so that it can be re-used following a fire. Of more immediate concern, prediction of the thermal response of building elements is the first step in the assessment of their mechanical response and ultimately the potential for structural failure and/or fire spread.

Detailed discussions of the mechanical response and potential for fire spread are provided in 6.3 and 6.4 respectively. However, it note that for some applications an assessment of the thermal response of building elements coupled with well-defined performance criteria may suffice. This may be the case, for example, if a structural member can be assumed to fail when it reaches a specific temperature as is often assumed for structural steel elements. It may also be the case if it can be assumed that the spread of fire from one enclosure to another may occur because of either the excessive transmission of heat through enclosure boundaries or because of openings created by the melting of materials as both of these phenomena can also be tied to temperature rise criteria. The question of establishing appropriate thermal criteria is briefly discussed in clause 8.

6.2.1.1 Input

As depicted in Figure 1, evaluation of the thermal response of building elements requires the following input data from the global information bus:

— building parameters (dimensions, locations, thermophysical and thermochemical properties of building elements);

— size of fire/smoke (for localized or external fires: physical size and relative location of fire to key building elements);

— thermal (for all fires: the temperature-time profile of fire gases and the heat flux impinging on building elements);

— pressure / velocity (the velocity of the fire gases may be needed to assess convective heat transfer from the fire to building elements); and

— effluent species (smoke concentrations effect the emissivity of the fire gases. The emissivity may be needed to assess radiative heat transfer from the fire to building elements).

6.2.1.2 Output

Once the evaluation of the thermal response of building elements is completed, the following data are passed to the global information bus:

— building condition (temperature-time profile within and on the surface of building elements).

This output also becomes input for assessing the mechanical response of building elements and the potential for fire spread.

6.2.2 Modelling the thermal response of building elements

As indicated in 6.2.1.1, to model the thermal response of building elements, a reasonably detailed description of the exposing fire is necessary. This document is intended to be used as part of a fire safety engineering assessment in which SS1 has first calculated the pertinent properties of the exposing fire (whether it be an enclosure fire, a localized fire or an external fire). There are, however, applications for which the exposing fire can be chosen from a set of design fires. Care must be exercised when selecting an appropriate design fire as some constructions may be sensitive to high temperatures whereas others may be sensitive to high rates of temperature rise or to the duration of exposure. Further guidance on the use of design fires is found in ISO/TR 13387-2.

Once the exposing fire has been chosen an assessment of the thermal response of building elements can begin (see Figure 1). The calculation of heat transfer to and within the building elements undertaken by SS3 will need to be more detailed than the calculation already undertaken by SS1 where it was the temperature of the fire gases that was of primary interest.

If a building element is in direct contact with fire gases (for example, in a post-flashover enclosure fire), heat is transferred to exposed surfaces of the element by means of radiation (see reference [1] in the bibliography) and convection (see reference [2]). On the other hand, if a building element is some distance from flames or hot gases (for example, for exposure to fire in a neighbouring building), “exposed” surfaces may be heated by radiation but cooled by convection. Engineering methods for modelling radiative and convective heat transfer for fire safety engineering calculations are readily available (see references [1] and [2]).

In either case, heat is transferred from the hot surface deeper into the element by means of heat conduction (see reference [3]). As heat is conducted into the element, any absorbed water is vaporized (a phase change) and the element itself may experience melting (a phase change) or thermal degradation. These processes are commonly endothermic and hence slow down heat transmission. The vapours generated by vaporization of water and by thermal degradation of the element will migrate through the element further impacting on the heat transfer process. In principle, then, heat transfer and mass transfer (gas flow) are coupled. The equations governing these processes are complex and can only be solved by the use of numerical methods.

For some materials, the internal processes discussed above are not present or do not unduly impact upon heat flow so that heat transfer through the material can be assumed to obey the 3-dimensional heat conduction (see reference [3]). Nonetheless, the material's thermal conductivity (k), specific heat (c) and perhaps even density (ρ) are commonly temperature dependent. Despite these simplifications, the heat conduction equation with temperature dependent coefficients can also only be solved by the use of numerical methods.

Analysis can be further simplified if the material's thermal properties (k, c and ρ) can be assumed to be constant (or at least can be replaced by an average value) over the temperature range of interest. Due to the complex nature of radiative heating at the surface (boundary conditions) the heat conduction equation can still only be solved explicitly by the use of numerical methods. Nonetheless, the structure of the equation reveals interesting dependencies on the thermal properties. For example, in the early stages of the heating, the increase of the temperature of a surface exposed to radiative and/or convective heating as a function of time is proportional to $(k \cdot \rho \cdot c)^{1/2}$; that is, to the inverse of the square root of the thermal inertia. On the other hand, the time-dependent temperature profile within the material can be shown to depend upon the material's thermal diffusivity κ.

For materials which have very large thermal conductivity or which are very thin, it is sometimes possible to completely ignore heat conduction. In such cases, a lumped heat capacity model can be constructed whereby the entire element is assumed to be at a uniform temperature. Nonetheless, the element is still heated at the surface by radiation and convection.

Further discussion of engineering methods for modelling the thermal response of building elements exposed to fire is provided in clause 7 of this part of ISO/TR 13387 and in ISO/TR 10158.

6.3 Mechanical response

6.3.1 Role in fire safety engineering design

This subclause provides an overview of the assessment of the mechanical response of building elements and the building structure when exposed to heating from fire. This analysis is undertaken using as input data the time-dependent temperature profiles within elements which have been calculated following the procedures outlined in 6.2.

The term mechanical response is used to denote two important facets of a building element's response to fire. Firstly, it is a measure of fire induced changes to the deflection, stiffness and load-bearing capacity of the element. Secondly, it is a measure of the development of openings (cracks) in the element as a result of the shrinkage (expansion) of materials, spalling, delamination, etc.

An accurate prediction of the mechanical response of building elements exposed to fire is essential in fire safety engineering design. In the first instance, it allows for an assessment of the degree of mechanical damage that may be sustained by building elements exposed to fire. This may be particularly important if a building is to be designed so that it can be re-used following a fire. Of more immediate concern, prediction of the mechanical response of building elements is necessary step in the assessment of the potential for structural failure and/or fire spread.

Detailed discussions of the potential for fire spread are provided in 6.4. However, it should be noted that for some applications an assessment of the thermal and, then, mechanical response of building elements coupled with well-defined performance criteria may suffice. This may be the case, for example, if a structural member can be shown to undergo excessive deflection. It may also be the case if it can be assumed that the spread of fire from one enclosure to another may occur because of openings created by the shrinkage (expansion) of materials, spalling, delamination, etc. The question of establishing appropriate criteria is briefly discussed in clause 8.

6.3.1.1 Input

As depicted in Figure 1, evaluation of the mechanical response of building elements requires the following input data from the global information bus:

- building parameters (mechanical properties of building elements, structural loads supported by building elements);
- building condition (temperature-time profile within and on the surface of building elements); and
- pressure and/or velocity (pressure distributions may have an impact on integrity and structural performance).

6.3.1.2 Output

Once the evaluation of the mechanical response of building elements is completed, the following data are passed to the global information bus:

- building condition (integrity of building elements and load-bearing capacity of building elements).

This output also becomes input for assessing the potential for structural collapse and fire spread.

6.3.2 Modelling the mechanical response of building elements

As indicated in 6.3.1.1, to model the mechanical response of individual building elements or of the building structure, the time-dependent temperature profiles within the elements are necessary. Although it is likely that in a fire safety engineering analysis these profiles will have been calculated following the procedures outlined in 6.2, such profiles are also available in graphical form for some elements exposed to the standard temperature-time curve defined in ISO 834-1 and for certain simulated natural fires.