



BSI Standards Publication

## **Application of fire safety engineering principles to the design of buildings**

Part 3: Structural response to fire and fire spread beyond the enclosure of origin (Sub-system 3)

**Publishing and copyright information**

The BSI copyright notice displayed in this document indicates when the document was last issued.

© The British Standards Institution 2019

Published by BSI Standards Limited 2019

ISBN 978 0 580 97727 5

ICS 13.220.20; 91.040.01

The following BSI references relate to the work on this document:

Committee reference FSH/24

Draft for comment 18/30373550 DC

**Amendments/corrigenda issued since publication**

Date	Text affected
<hr/>	

# Contents

	Page
<b>Foreword</b>	<b>iv</b>
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Symbols	4
5 Design approach to PD 7974-3	7
5.1 General	7
5.2 Interaction with BS 7974 framework	7
<i>Figure 1 — Interaction between the various professions and the design team in addressing PD 7974-3 factors</i>	7
5.3 Functional objectives	7
5.4 Identification of fire hazards and possible consequences	8
5.5 Identification of acceptance criteria and appropriate methods of analysis	8
5.6 Establishing trial fire safety designs	9
5.7 Establish fire scenarios for analysis	9
5.8 Analysis	10
<i>Figure 2 — Procedure for analysis within PD 7974-3</i>	10
6 Analysis methods	11
6.1 General	11
6.2 Basis of analysis	11
6.3 Accuracy	12
6.4 Means	12
6.5 Measures	13
7 Evaluation of fire conditions	13
7.1 Design fire characterization	13
7.2 Selection of design fires	13
<i>Figure 3 — Gas temperature in non-combustible and combustible compartments [8]</i>	15
8 Evaluation of thermal response	15
8.1 Thermal response of elements within enclosure	15
8.2 Empirical data	15
8.3 Simplistic calculations	16
8.4 Advanced calculations	17
8.5 Quantitative analysis of heat flow by conduction	17
8.6 Quantitative analysis of heat flow by convection	19
8.7 Quantitative analysis of heat flow by radiation	19
8.8 Characterizing the condition of fires spreading from openings in enclosures	20
9 Behaviour of separating elements in fire	21
9.1 Behaviour of fire-resisting separating elements	21
9.2 Maintaining the separating capability of elements or constructions	33
<i>Figure 4 — Typical detail showing protection to a floor beam with a service penetration</i>	35
9.3 Behaviour of non-fire-resisting separating elements	36
<i>Table 1 — Notional period of fire endurance for which imperforate condition can be assumed for unproven elements subject to fire exposure</i>	36
10 Analysis of structural response of loadbearing structural elements and frames	37
10.1 Concepts	37
<i>Table 2 — Partial safety factors for loads (PD 6688-1-2:2007, Table 1)</i>	38
10.2 Acceptance criteria	39
10.3 Methods for determining structural response	40

	<i>Figure 5 — Maximum steel temperature concept</i>	42
	<i>Table 3 — Values of <math>k_b</math></i>	42
	<i>Figure 6 — General approach to structural fire safety design</i>	45
<b>Annex A</b>	<b>(informative) Fire spread mechanisms</b>	<b>49</b>
	<i>Figure A.1 — Routes for fire transmission</i>	51
<b>Annex B</b>	<b>(informative) Design fires</b>	<b>53</b>
<b>Annex C</b>	<b>(informative) Heat transfer (and thermal response) of specific materials</b>	<b>54</b>
	<i>Table C.1 — Guidance on the material surface emissivity of construction materials</i>	54
	<i>Figure C.1 — Configuration factors for typical scenarios</i>	55
	<i>Figure C.2 — Calculation of section factors</i>	60
	<i>Table C.2 — Calculation of element factors (EF)</i>	61
	<i>Figure C.3 — Calculation of element factors</i>	62
	<i>Table C.3 — Typical set of coating thicknesses for a profile non-reactive spray-applied protection system</i>	63
	<i>Figure C.4 — Typical set of board thicknesses for a box encasement fire protection system</i>	64
	<i>Figure C.5 — Compartment parameters</i>	67
	<i>Table C.4 — Location of columns between windows to avoid direct flame impingement</i>	67
	<i>Figure C.6 — Spandrel beam with shielded flanges</i>	68
	<i>Table C.5 — Spandrel beams</i>	68
	<i>Figure C.7 — Calculation methods for determining the temperature profiles through masonry elements</i>	71
	<i>Figure C.8 — Temperature gradient through autoclaved concrete masonry with a density of 400 kg/m<sup>3</sup> to 800 kg/m<sup>3</sup></i>	72
<b>Annex D</b>	<b>(informative) Temperature-dependent properties of non-loadbearing construction systems — Thermal properties of materials used in composite sandwich panels</b>	<b>77</b>
	<i>Table D.1 — Comparison of expansion of materials used in composite sandwich panels</i>	77
	<i>Table D.2 — Comparison of specific heat capacity of materials used in composite sandwich panels</i>	78
	<i>Table D.3 — Thermal conductivity for various densities of mineral (rock) wool at elevated temperatures</i>	78
	<i>Figure D.1 — Thermal conductivity for various densities of mineral (rock) wool at elevated temperatures</i>	79
	<i>Table D.4 — Constants for calculating the thermal conductivity of mineral wool at elevated temperatures</i>	79
	<i>Table D.5 — Thermal conductivity of cellular glass</i>	79
	<i>Table D.6 — Thermal conductivity of expanded polystyrene</i>	80
	<i>Table D.7 — Thermal conductivity of extruded polystyrene</i>	80
	<i>Table D.8 — Thermal conductivity of phenolic foam</i>	80
	<i>Table D.9 — Thermal conductivity of polyisocyanate foam</i>	80
	<i>Table D.10 — Thermal conductivity of rigid polyurethane foam</i>	80
	<i>Table D.11 — Thermal conductivity through the cell gas for various blowing gases</i>	81
	<i>Table D.12 — Typical densities of core materials used in sandwich panels</i>	81
<b>Annex E</b>	<b>(informative) Structural response of specific materials</b>	<b>82</b>
	<i>Figure E.1 — Design methods for fire limit state (FLS) design adopted in BS EN 1992-1-2</i>	83
	<i>Figure E.2 — Principle design methodologies adopted in BS EN 1993-1-2</i>	85
	<i>Figure E.3 — Schematic representation of the compressive and tensile forces of a floor zone during fire</i>	90
	<i>Figure E.4 — Illustration of the deflection of a multi-zone composite floor system with protected and unprotected members</i>	91

	<i>Figure E.5 — Illustration of catenary action developed in a multi-zone composite floor system</i>	92
	<i>Table E.1 — Notional char depths for various species after 30 min and 60 min in the standard furnace test (BS 476-20)</i>	95
	<i>Table E.2 — Values of <math>k_{fi}</math> for different components/elements</i>	96
	<i>Figure E.6A — Definition of residual cross-section and effective cross-section</i>	97
	<i>Figure E.6B — Relationship between <math>k_0</math> and time of fire exposure for unprotected surfaces, and for protected surfaces where <math>t_{ch} \leq 20</math> min</i>	98
	<i>Figure E.6C — Relationship between <math>k_0</math> and time of fire exposure for protected surfaces where <math>t_{ch} &gt; 20</math> min</i>	98
	<i>Table E.3 — Determination of <math>k_0</math></i>	98
	<i>Figure E.7 — Equations (E.17) to (E.19) illustrated</i>	99
<b>Annex F</b>	(informative) <b>Fire resistant load bearing structural solutions</b>	<b>105</b>
<b>Annex G</b>	(informative) <b>Methodology for establishing the extended application of fire resistance test results</b>	<b>107</b>
	<b>Bibliography</b>	<b>114</b>

### Summary of pages

This document comprises a front cover, and inside front cover, pages i to vi, pages 1 to 118, an inside back cover and a back cover.

---

# Foreword

## Publishing information

This Published Document is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 March 2019. It was prepared by Technical Committee FSH/24, *Fire Safety Engineering*. A list of organizations represented on this committee can be obtained on request to its secretary.

## Supersession

This Published Document supersedes PD 7474-3:2011, which is withdrawn.

## Relationship with other publications

This Published Document is one of a series of documents published under the Fire Standards Policy Committee, and is a supporting document to BS 7974, *Application of fire safety engineering principles to the design of buildings — Code of practice*.

Other documents in the series are:

PD 7974-1: *Initiation and development of fire within the enclosure of origin*;

PD 7974-2: *Spread of smoke and toxic gases within and beyond the enclosure of origin*;

PD 7974-4: *Detection of fire and activation of fire suppression systems*;

PD 7974-5: *Fire service intervention*;

PD 7974-6: *Evacuation*;

PD 7974-7: *Probabilistic risk assessment*.

Where appropriate, references to relevant standards are provided in order to assist the reader in understanding the design methodologies presented and to compare different approaches or sources of data. It is therefore important that PD 7974-3 is not used in isolation and reference is made to the relevant standards, particularly in relation to additional notes and subclauses describing its application.

## Information about this document

This is a full revision of the standard, and introduces the following principal changes:

- the content has been updated to include the recommendations in the latest standards and guidance documents;
- design fires for structural fire engineering have now been integrated with PD 7974-1 and a new section on design fire selection process has been introduced. Additionally, the inherent assumptions and limitations of adopting these design fires have been explicitly stated;
- the information on potential mechanisms for fire spread has been expanded;
- the potential use of risk-based concepts described in PD 7974-7 has been added for the purposes of PD 7974-3;
- information such as material properties that was available in other British Standards has been removed to avoid repetition and reduce the length of the document;
- the layout of the document has been re-arranged so that self-contained technical information is provided as an annex.

This and the other Published Documents (PDs) in this series contain guidance and information on how to undertake quantitative and detailed analysis of specific aspects of design. It is intended that they be updated as new theories, calculation methods and/or data become available.

However, it is important to recognize that the information contained within PD 7974-3 does not preclude data, information or methods of analyses from other sources, such as published peer reviewed research, manufacturers' data or codes of practice prepared on behalf of the construction materials industry, professional engineering and technical institutions and other professional bodies.

BS 7974 was first published in 2001. Since then there have been substantial changes in understanding in the behaviour of fire in the built environment and how materials and construction systems respond at elevated temperatures. Not least, the structural Eurocodes on Fire Actions have been published as full European Standards. These have resulted in revised formulations on the behaviour of structural components in fire, as well as new data on the thermal and mechanical properties of the various materials used in building construction. One of the most significant and recent advances in the understanding of buildings in fire has come about as a result of studies of experimental major fires in full size structures and the ensuing guidance this has generated on analysing the structural behaviour of the framework and compartmentation.

However, where understanding the behaviour of construction systems and building products cannot be quantified, or there are no specific analyses of some aspects of fire spread beyond the enclosure of origin other than the performance of products based upon a fire resistance furnace test, a commentary is given on the particular issues that need to be considered and how these could be treated.

A fire safety engineering approach that takes into account the total fire safety package can provide a more economical solution than prescriptive approaches to fire safety. In some cases, it is the only viable means of achieving a satisfactory standard of fire safety in some large and complex buildings.

A major issue in the determination of the structural response is the application of time equivalent methods in specifying an equivalent period of heating in the standard fire resistance test furnace. Any outputs need to consider the consequences of failure in relation to the particular occupancy and building dimensions (height and compartment size) and its location in the building, for example, BS 9999 specifies a risk-based approach for occupant life safety in building structures.

Fire safety engineering has many benefits. The use of BS 7974 facilitates the practice of fire safety engineering and, in particular:

- a) provides the designer with an organized approach to fire safety design;
- b) allows the safety levels for alternative fire safety designs to be compared;
- c) provides a basis for selection of appropriate fire protection systems;
- d) provides opportunities for innovative design; and
- e) provides information on the management of fire safety for a building.

Fire is an extremely complex phenomenon and there are still gaps in the available knowledge. When used by suitably qualified and competent persons experienced in fire safety engineering, BS 7974 and its associated PDs provide a means of establishing acceptable levels of fire safety economically, without impeding building design.

For the purpose of this Published Document, spread of fire beyond the enclosure of origin is deemed to have taken place when any material outside of the fire enclosure ignites or suffers thermal degradation. Structural response is the interaction of loadbearing and non-loadbearing elements or frames as a result of thermal and/or mechanical actions due directly or indirectly to a fire. The level of sophistication employed to evaluate fire spread can vary. For example, a simple decision can be

taken that the creation of any openings or gaps in the enclosure boundaries precipitates fire spread. Alternatively, more complex analyses can be employed to consider whether flames project from openings in the enclosure's boundaries and whether such flames ignite or degrade materials outside the enclosure.

### **Use of this document**

As a guide, this part of PD 7974 takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

This publication is not to be regarded as a British Standard.

### **Presentational conventions**

The provisions of this Published Document are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

*Commentary, explanation and general informative material is presented in smaller, italic type, and does not constitute a normative element.*

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

### **Contractual and legal considerations**

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

**Compliance with a Published Document cannot confer immunity from legal obligations.**



---

## 1 Scope

This Published Document provides a framework for developing a rational methodology for design using a fire safety engineering approach through the application of scientific and engineering principles to the protection of people, property and the environment from fire. This Published Document considers the following issues:

- a) the conditions that lead to fire spread beyond the enclosure of fire origin (see also [Annex A](#));
- b) the selection of design fires depending on the objectives of the assessment (see also [Annex B](#));
- c) the thermal and mechanical response of the enclosure boundaries and its structure to the fire conditions (see also [Annex C](#) and [Annex D](#));
- d) the impact of the anticipated thermal and mechanical responses on adjacent enclosures and spaces; and
- e) the structural responses of loadbearing elements and their effect on structural stability, load transfer and acceptable damage according to the design and purpose of the building (see also [Annex E](#) and [Annex F](#)).

[Annex G](#) provides a methodology for establishing the extended application of fire resistance test results.

---

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN ISO 13943, *Fire safety — Vocabulary*

---

## 3 Terms and definitions

For the purposes of this Published Document the terms and definitions given in BS EN ISO 13943 and the following apply.

### 3.1 calculations (in support of extended application)

calculation methods that can be applied to one or more parameters of a tested construction and which are based on existing physical laws, or have been empirically validated and form part of the process of defining the extended application

### 3.2 consequence

damage that would occur if the structural failure has occurred or the time-equivalent period has been exceeded

*NOTE With respect to Approved Document B of the Building Regulations for England & Wales [1], consequence is directly proportional to height.*

### 3.3 construction parameter

aspect of the design and construction of an element that can be varied and which can result in a change in the fire resistance performance

*NOTE For example, a change in one or more of the dimensions of a stud in a stud framed separating element.*