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Computational structural fire design — Review of calculation models, fire tests for determining input material data and needs for further development

Conception de calcul des feux de structures — État des travaux des modèles de calcul et d'essais au feu pour la détermination des données de base requises et des besoins du développement ultérieur

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Foreword

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In exceptional circumstances, 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), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 12471 was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

Introduction

Considerable advances have been made in recent years in understanding the behaviour of fires in their development and impact upon buildings. Coupled with developments in computational techniques, it is now possible to predict how structures will behave at the fire limit state (i.e. under fire conditions).

As a result of the high level of international fire research in recent decades, more and more components and systems are becoming amenable to analytical and computer modelling. Considerable progress has been made concerning such phenomena and procedures as:

- reaction of materials to fire;
- fire growth in a compartment;
- fully developed compartment fire;
- fire spread between buildings;
- fire behaviour of load-bearing and separating building structures;
- smoke filling in enclosures and smoke movement in escape routes and multi-storey buildings;
- interaction of sprinklers and fire, including sprinkler and fire venting interaction;
- process of escape; and
- systems approach to the overall fire safety of a building, in its most general form comprising fire development models interacting with human response models.

This progress in fire research has led to consequent changes in the field of codes, specifications, and recommendations for fire engineering. Some characteristic trends in these changes are:

a) improved connection to real fire scenarios;

b) increase in extent of design, based on functional requirements and performance criteria;

c) development of new test methods, that are, as far as possible, material-independent and related to well-defined phenomena and properties;

d) increase in application of reliability-based analytical design;

e) extended use of integrated assessments; and

f) introduction of goal-oriented systems of analysis of total, active and passive fire protection for a building.

The most manifest verification of these developing trends probably relates to the fire engineering design of load-bearing and separating structures. An analytical determination of the fire resistance of structural elements is being approved by authorities in more and more countries as an alternative to the internationally predominant design that is based on the results of the standard fire resistance test and connected classification. The further step to permit a general practical application of an analytical design, based on a natural compartment fire concept, was taken by Swedish authorities as early as 1967. Since then, a few other countries have been officially open to the possibility of structural fire design.

A significant contribution was made by the Fire Commission of the Conseil International du Bâtiment, CIB W14, in the form of a state-of-the-art report, in 1983. The report presented a conceptual approach towards a probability-based design guide on structural fire safety[1], supplemented in 1986 by a model code/design guide[2]. These design guides are important aids in drafting corresponding national regulations and recommendations. For European countries, the Eurocodes (see references [3] to [10] in the Bibliography) issued as European Prestandards and supplemented with national application documents, certainly will contribute to increased practical use of analytical structural fire design methods.

A problem arises between material-related codes and the general code. The material-related codes focus very strongly on the fire design, based on thermal exposure according to the standard fire resistance test. However, the general code, specifying the basis of design and mechanical and thermal actions on fire-exposed structures, also gives some guidance, in the form of informative annexes, regarding the alternate structural fire design, based on a parametric fire exposure determined by fire models or specified temperature-time curves.

An analytical fire engineering design can now be performed in most cases for steel structures. Validated material models for the mechanical behaviour of concrete under transient high-temperature conditions[11] to [13] and thermal models for a calculation of the charring rate in wood exposed to fire[14] to [16], developed in recent decades, have significantly enlarged the area of practical application of an analytical structural fire design. To support this application, design diagrams and tables have been computed and published, giving directly, on the one hand, the temperature state of the fire-exposed structure, and on the other, a further transfer to the corresponding load-bearing capacity of the structure, for instance see references [17] to [47] in the Bibliography.

The following clauses begin with a summary of internationally applied methods for a structural fire engineering design. With this survey as general background, the characteristics of a reliability-based approach are described. In order to review the need for further development of calculation models and for fire tests to get the input data required for the design, the design alternative, based on a simulated fire exposure, has been chosen for presentation. For other design alternatives, applied in practice, the need for calculation models and related input data is less comprehensive than for the more general approach being dealt with. The presentation is followed by a discussion about uncertainty in the design process.

Following this background presentation of the reliability-based design process and its inherent uncertainties, the remaining document is devoted to related deterministic models, comprising the fire exposure and the thermal and mechanical behaviour of the structure. These models are supplemented with a survey of the material input data required for the structural fire engineering design. Finally, conclusions are drawn regarding the need for further development of calculation models and tests to determine the input material data required for the structural fire design.

Computational structural fire design — Review of calculation models, fire tests for determining input material data and needs for further development

1 Scope

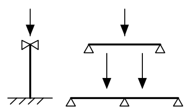
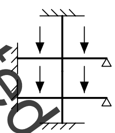
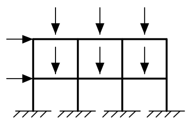
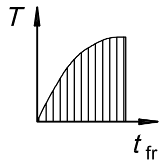
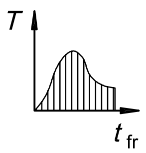
This Technical Report gives a review of the advances that have been made in measuring and understanding how structural materials respond to fire in terms of changes in their elevated temperature, and physical and mechanical characteristics, and to identify areas where further work is necessary to generate the data required. Analytical methods for heat transfer are combined with mechanical models to calculate structural behaviour from single elements up to complete frames under real fire and ISO Standard furnace heating conditions. This Technical Report reviews advances in computational analysis and indicates how these can be used with probabilistic analysis to provide a risk-based approach to structural fire engineering design.

2 Internationally applied methods for structural fire engineering design

The methods available at present for a structural fire engineering design can systematically be characterized with reference to the matrix according to Table 1 [1] [2] [37].

The matrix is based on two types of models for the thermal exposure of the structure (H1 and H2) and three types of models for the mechanical behaviour of the structure (S1, S2 and S3).

Table 1 — Matrix of thermal exposure and structural behaviour models, characterizing available methods for structural fire engineering design

Model for thermal exposure		**Model for structure**		
		S1	S2	S3
		Element	Substructure	Complete structure
				
H1	Nominal temperature-time curves 	Test or calculation (deterministic)	Calculation exceptionally testing (deterministic)	
H2	Real fire 	Calculation (probabilistic)	Calculation (probalistic)	Calculation (probabilistic) in special cases and for research

