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A parametric natural fire model for the structural fire design of multi-storey buildings

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Abstract

A parametric natural fire model is presented, which is derived on the basis of simulations with heat balance models for realistic natural design fires, taking into account the boundary conditions of typical compartments in residential and office buildings. These so-called iBMB parametric fire curves are formulated with the help of simplified empirical equations which can easily be used for structural fire design as part of a performance-based natural fire design concept. The iBMB parametric fire curves are checked and validated by comparison with results of different heat balance models and with published fire tests from different fire research laboratories. In addition, a natural fire test in a test room with ordinary office room furnishings has been performed which supports the parametric natural fire model presented here. The application of the iBMB parametric fire curves is demonstrated by means of an example.

Keywords: Simplified natural fire model; Structural fire design; Design fire; iBMB parametric fire curve

1. Introduction

Within a performance-based fire design concept the structural design should be based on a natural design fire which is representative for the boundary conditions of a given building. The ‘‘traditional way’’ of structural fire design using the ISO 834 temperature–time curve in many cases results in a design on the safe side causing unsatisfactory costs for fire protection measures, e.g. greater concrete cover of reinforced concrete elements, thicker cladding or over-dimensioning of steel elements, which entails economic as well as aesthetical disadvantages. In some cases the structural fire design with ISO 834 temperature–time curve can result in under-estimation of the thermal exposure.

In this paper a parametric natural fire model called *iBMB parametric fire curve* [1,2] is presented. It considers the actual boundary conditions of the fire compartment concerning fire load, ventilation conditions, geometry and thermal properties of the enclosure. The iBMB parametric fire curves are derived by heat balance simulations assuming a great number of natural designs fires by varying the above-mentioned parameters. The iBMB parametric fire curves are appropriate to describe the thermal action of natural fires in residential and office buildings including realistic room-to-room fire spread. Contrary to the Eurocode 1 parametric temperature–time curves, the iBMB parametric fire curves are directly derived from the rate of heat release defining the design fire.

Because of the connection between design fire and parametric fire curve, all events influencing the natural fire and resulting in a variation of the rate of heat release can be considered by the iBMB parametric fire curves. Thus the iBMB parametric fire curves can also be used to consider the occurrence of flashover, the breakage of windows with additional ventilation, a failure of the enclosure with loss of compartmentation or the effect of fire fighting and sprinkler systems. Whilst the iBMB parametric fire curves are valid for the structural fire design of each kind of structure, they offer the most benefit for steel structures.

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Nomenclature

A_f	floor area of fire compartment, m^2
A_t	total area of the enclosing components including openings, m^2
A_T	total area of the enclosing components without openings, m^2
A_w	area of ventilation openings, m^2
H_{net}	net calorific value, MJ/kg
O	opening factor ($A_w h_w^{1/2}/A_t$), m$^{1/2}$
Q	fire load, MJ
$\dot{Q}$	rate of heat release, MW
$\dot{Q}_{f,A}$	rate of heat release per unit area, fuel-controlled fire, MW/m^2
$\dot{Q}_{\max}$	maximum rate of heat release, MW
$\dot{Q}_{\max,f}$	maximum rate of heat release, fuel-controlled fire, MW
$\dot{Q}_{\max,v}$	maximum rate of heat release, ventilation-controlled fire, MW
$\dot{Q}_v$	rate of heat release, ventilation-controlled fire, MW
T	temperature, °C
b	averaged thermal property of the enclosing components, J/(m^{2}s$^{0.5}$K)
h_w	averaged height of the ventilation openings, m
$\dot{m}$	mass burning rate, kg/s
m_a	mass flow into the fire compartment, kg/s
$\dot{m}''$	mass burning rate per unit area, kg/(m^{2}s)
q''	fire load density, MJ/m^2
r	stoichiometric fuel/air ratio, dimensionless
t	time, s
t_g	time of fire growth to 1 MW, s
χ	combustion efficiency, dimensionless

2. Natural fires in multi-storey buildings

2.1. Temperature–time curves

The standard temperature–time curve according to ISO 834 was developed in the 1930s summarising data from fires in residential, office and commercial buildings. The curve should cover most of the potential courses of fires in common buildings. As fire tests have shown, the maximum temperature of a natural fires can exceed the ISO-curve, but after the maximum it decreases again, whereas the ISO-curve rises continuously (Fig. 1).

Magnusson et al. [3] published curves describing the temperature development of natural fires on the basis of mass and energy balance equations. These curves have been incorporated into a Swedish standard and have served also as the basis for the parametric temperature–time curves of Eurocode 1-1-2 [4]. Latter can be applied to the structural fire design of small to medium rooms where a fully developed fire is assumed.

The parametric temperature–time curves of Eurocode 1-1-2, annex A in some cases provide an unrealistic temperature increase and decrease. One reason is that for fuel-controlled fires in residential and office buildings the maximum temperature is fixed at a fire duration of 20 min. For fire compartments with large openings and an enclosure with low thermal conductivity the Eurocode gives an extremely fast enhancement and decay of the temperature. For fire compartments with small openings and an enclosure with high thermal conductivity; however, an extremely slow decay of the temperature is assumed. The parametric temperature–time curves in Eurocode 1-1-2 [4] only describe the fully developed phase of the fire without considering the growth phase. Results of fire tests

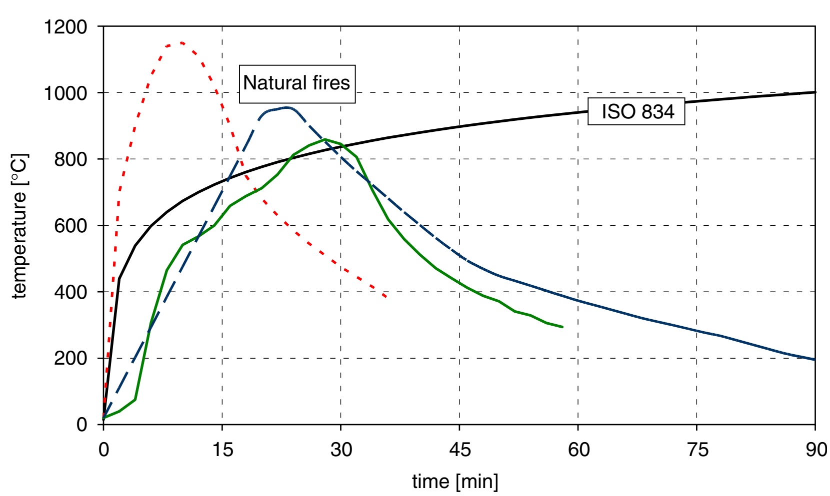

Fig. 1. Comparison of temperature–time curves in natural fires with ISO 834 standard fire.