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Determination of design fires in compartments with combustible structure – modification of existing design equations

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1 Introduction

The determination of the fire development, i.e. the temperature-time curve, is an essential input for the fire design of structural elements when performance based design (PBD) is used. PBD uses the particular boundary conditions (i.e. geometry, openings, and fire load) of a compartment to define a relevant temperature development. This may be done according to EN 1991-1-2 Annex A or another method such as the corresponding German National Annex. Regardless the method, the consideration of the contribution of the structural fire load is required by EN 1991-1-2. The increase of the movable fire load by the structural fire load for timber corresponding a charring depth was mentioned by several authors (K. Leikanger -Friquin 2012, Brandon 2018, McNamee et al 2019). However, various approaches exist. This paper gives guidance about how to include the contribution of unprotected timber surfaces in the actual framework of EN 1995-1-2. Here, the estimation of the a) maximum heat release and b) the calculation of the fire load density are extended and c) the amount of heat released at the façade is given.

2 Background and state of the art

a. Available design models determine whether the fire is ventilation or fuel controlled. This because the burning rate of a solid is limited either by the availability of oxygen or the maximum production rate of combustible volatiles, i.e. surface-volume-share of the particular type of fire load; the minimum is decisive. Whenever the enclosure condition show low oxygen access but combustible volatiles are created exceeding the required oxygen for the combustion, significant flaming at the façade exterior the compartment can be observed. Thus, all oxygen entering the compartment is consumed, a certain share of the combustion occurs exterior and the ventilation characteristics control the fire, i.e. a ventilation controlled fire.

b. The fire load density considers the available fire load per floor area depending on the occupancy of the compartment. No further guidance is given for the consideration of combustible surfaces, i.e. the heat release rate of structural timber with a low ratio volume to surface.

2.1 Limitation of available methods

This note focuses on the physically based fires in general and the parametric fire of EN 1991-1-2 in particular. In the method, an opening factor considers the compartment geometry including the opening. The opening height is a crucial variable as it allows the discharge of hot gases and the entry of oxygen. The parametric fire time-temperature curve can be considered as a deformed in its height (modified temperature increase due to the thermal inertia) and length (depending on the availability of a fire load). For a timber structure, it would be conservative to assume that the structure represents an addition to the movable fire load. It seems scientifically more appropriate to consider the increase of the fire load using the charcoal depth. Recently, the iteration process required for the parametric fire design was described by Brandon et al. (2018). Verifying the approach with a series of large compartment experiments Brandon et al. introduced a combustion share of 0.7 to fit the measurements. With a deviating approach, McNamee et al. (2019) propose a combustion efficiency factor between 0.7 and 0.9 to fit their measurements.

3 Extended Eurocode Design

a) The floor related design value of the fire load density $q_{f,d}$ is currently defined:

$$q_{f,d} = q_{f,k} \cdot m \quad [\text{MJ/m}^2] \tag{1a}$$

where

$q_{f,k}$ is the characteristic fire load density,

m is the combustion factor set to 0.8 for mainly cellulosic materials, thus even for timber. For the actual extension, the factors taking into account the fire activation risk and the different active firefighting measures are not included in Eq. (1a).

To consider combustible surfaces in the compartment Eq. (1a) should be extended to:

$$q_{f,d} = (q_{f,k} + q_{c,k}) \cdot m \quad [\text{MJ/m}^2] \tag{1b}$$

where $q_{c,k}$ is the additional fire load due to the combustible structure which is set to:

$$q_{c,k} = A_c \cdot s \cdot \beta \cdot t \cdot \alpha / A_f \quad [\text{MJ/m}^2] \tag{1c}$$

where

A_f is the floor area of the fire compartment, in m^2,

A_c is the area of the combustible surfaces, in m^2,

s is the specific heat release rate derived to s=0.13 $\frac{\mathrm{MW}}{\mathrm{m}^2}/\frac{\mathrm{mm}}{\mathrm{min}}$ based on a wood density of 450 kg/m^3 and the heat of combustion of wood 17.5 MJ/kg,

t is the relevant time of fire exposure, in sec (e.g. with temperatures higher than 300°C),

β is the charring rate, in mm/min.

Further, a correction factor α < 1 should be implemented to account for the combustion boundary conditions (reduced heat release of structural elements with a low ratio volume to surface in comparison to the movable fire load. Brandon (2018) proposed a combustion share factor of 0.7; however, a slightly different description of the heat release density was used. Conservatively, in Eq. (1c) α=1.0 can be used.

b) Correspondingly, the maximum heat release rate for fuel-controlled fires is defined:

$$Q_{\max,f,k} = HRR_f \cdot A_f + HRR_{timber} \cdot A_c \quad [\mathrm{MW}] \tag{2a}$$

where HRR_{timber} is the heat release rate of timber for a certain charring rate:

$$HRR_{timber} = s \cdot \beta \quad [\mathrm{MW/m^2}] \tag{2b}$$

The terminology in Equations (1) and (2) follows the design procedure of Eurocode and its content based on straight forward physics. In contradiction to McNamee et al. (2019) a variable HRR for timber is proposed instead of a charring rate of 1.5 mm/min and the combustion factor is considered to be valid for the fire load irrespectively the source (movable or structural fire load). The factor α should be determined by calibration to experimental results and will be provided in the new Eurocode 5 replacing the version 2002.

4 References

Brandon D, Koji K, Hakkarainen T (2018): Performance based design for mass timber structures in fire Design - Calculation Example, COST FP1404 document N214-07. DOI 10.3929/ethz-b-000319459

McNamee, R, Zehfuss, J, Bartlett A, Heidari, M, Robert, F, Bisby, L (2019): Enclosure fire dynamics with a combustible ceiling, INTERFLAM 2019 proceedings, London.

Eurocode 1 (2002): Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire. CEN. (EN 1991-1-2).

Eurocode 5 (2004): Design of timber structures - Part 1-2: General - Structural fire design. CEN. (EN 1995-1-2).