Second Semester Examination
2020/2021 Academic Session

July/August 2021

# EAF525 – Structural Design for Fire Safety

Duration : 2 hours

Please ensure that this examination paper contains **SEVEN (7)** printed pages before you begin the examination.

**Instructions:** This paper contains **THREE (3)** questions. Answer **ALL** questions.

All questions **MUST BE** answered on a new page.

1. Develop a parametric fire curve for a fire compartment in an office building as shown in **Figure 1** in accordance with EN 1991-1-2. The floor and ceiling are made from reinforced concrete. The wall is made of solid bricks and has 2 windows. The size of all windows is the same. The thermal properties of the floor, ceiling, and walls are given in **Table 1**. Clearly state any assumptions made and indicate the related Clause, Annex, and Table of the referred Codes considered in developing the parametric fire curve.

(35 marks)

**Table 1**. Thermal properties

| **Component** | **Density ($kg/m^3$)** | **Specific heat ($J\ kg^{-1}\ K^{-1}$)** | **Thermal conductivity ($W\ m^{-1}\ K^{-1}$)** |
|---|---|---|---|
| Floor | 2300 | 1000 | 1.6 |
| Ceiling | 2300 | 1000 | 1.6 |
| Wall | 1600 | 840 | 0.7 |

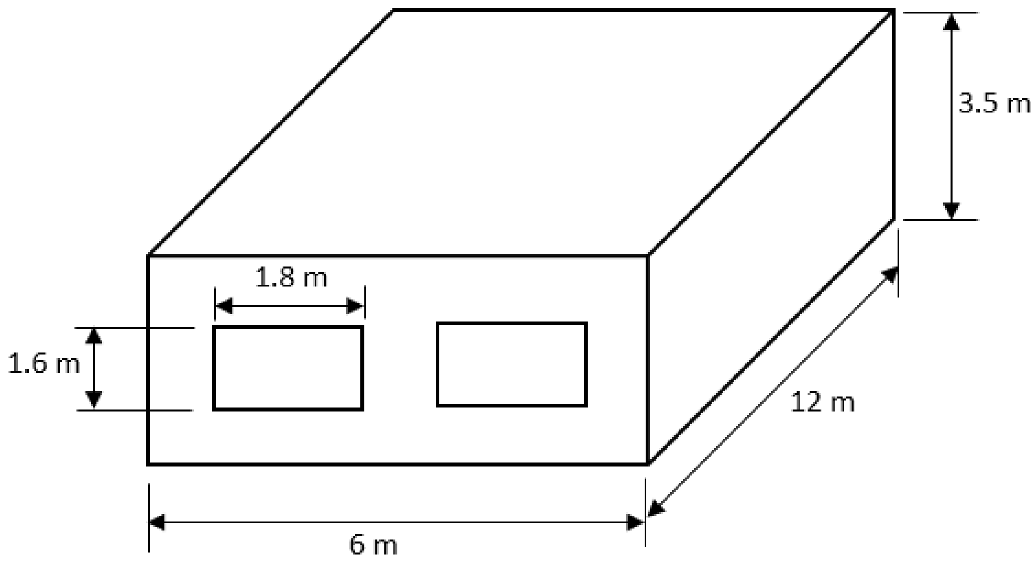


**Figure 1**

**2.** **Figure 2** shows a reinforced concrete slab supported by precast concrete tee-beams. The precast tee-beams are supporting a simply supported reinforced concrete slab over a span of 6.0 m, carrying dead and live loads of 4.8 kPa (including its self-weight) and 3.0 kPa, respectively. Estimate the required restraint condition for a fire resistance rating of 90 min.

Given:

| | |
|---|---|
| Span of slab | $L = 6.0$ m |
| Overall depth | $h = 300$ mm |
| Concrete density | $\rho = 24$ kN/m$^3$ |
| Characteristic strength of concrete | $f_{ck} = 30$ MPa |
| Yield stress | $f_{yk} = 410$ MPa |
| Diameter of reinforcement | $D_b = 16$ mm |
| Web width | $b_w = 200$ mm |
| Overall width | $b_f = 1200$ mm |
| Cross-sectional area | $A = 85\ 000$ mm$^2$ |
| Modulus of Elasticity of concrete | $E = 30$ GPa |
| Head perimeter | $s = 1550$ mm |

[35 marks]

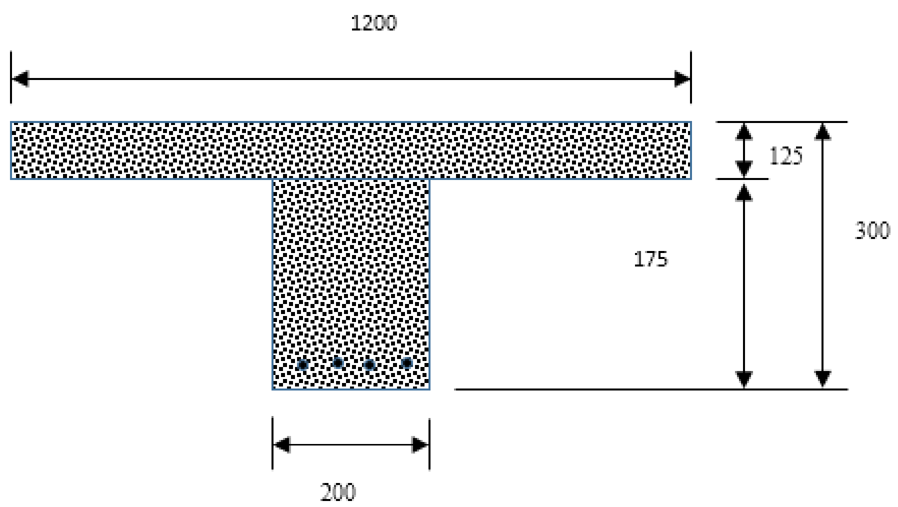


**Figure 2 (all dimensions in mm)**

3. (a). Thermal expansion of material is one of the important material properties that need to be considered in structural design for fire safety. Discuss the effect of thermal expansion and how this issue is addressed in fire protection of steel structure.

[10 marks]

(b). Calculate the fire severity using Eurocode for a 5.0 m × 6.0 m × 3.5 m high reinforced concrete compartment in a building. The compartment has 3 windows 1.2 m × 2.0 m each, a roof opening 1.2 m × 1.2 m and a fire door 1.2 m × 2.1 m. Take the design fire load, $q_{f,d}$ = 800 MJ/m$^2$, thermal conductivity of concrete, $k$ = 1.5 W/mK, concrete density, $\rho$ = 2400 kg/m$^3$ and specific heat, $c_p$ = 880 J/kgK. If the standard fire resistance of all structural members is R 60, comment your findings. Please refer to **Appendix 1**.

[20 marks]

## APPENDIX 1

(3) The equivalent time of standard fire exposure is defined by:

$t_{e,d} = (q_{f,d} \cdot k_b \cdot w_f)\ k_c$ or

$$t_{e,d} = (q_{t,d} \cdot k_b \cdot w_t)\ k_c \qquad \text{[min]} \qquad \text{(F.1)}$$

where

$q_{f,d}$ is the design fire load density according to annex E, whereby $q_{t,d} = q_{f,d} \cdot A_f / A_t$

$k_b$ is the conversion factor according to (4)

$w_f$ is the ventilation factor according to (5), whereby $w_t = w_f \cdot A_t / A_f$

$k_c$ is the correction factor function of the material composing structural cross-sections and defined in Table F.1.

**Table F.1 — Correction factor $k_c$ in order to cover various materials.**
**($O$ is the opening factor defined in annex A)**

| Cross-section material | Correction factor $k_c$ |
|---|---|
| Reinforced concrete | 1,0 |
| Protected steel | 1,0 |
| Not protected steel | $13{,}7 \cdot O$ |

**Table F.2 — Conversion factor $k_b$ depending on the thermal properties of the enclosure**

| $b = \sqrt{\rho c \lambda}$ [J/m$^2$s$^{1/2}$K] | $k_b$ [min · m$^2$/MJ] |
|---|---|
| $b > 2\,500$ | 0,04 |
| $720 \le b \le 2\,500$ | 0,055 |
| $b < 720$ | 0,07 |

(5) The ventilation factor $w_f$ may be calculated as:

$$w_f = ( 6,0 / H )^{0,3} [0,62 + 90(0,4 - \alpha_v)^4 / (1 + b_v \alpha_h)] \geq 0,5 \quad [-] \quad (F.3)$$

where

$\alpha_v = A_v / A_f$ is the area of vertical openings in the façade ($A_v$) related to the floor area of the compartment ($A_f$) where the limit $0,025 \leq \alpha_v \leq 0,25$ should be observed

$\alpha_h = A_h / A_f$ is the area of horizontal openings in the roof ($A_h$) related to the floor area of the compartment ($A_f$)

$b_v = 12,5 (1 + 10 \alpha_v - \alpha_v^2) \geq 10,0$

$H$ is the height of the fire compartment [m]

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