1.8 Selected aspects of safety evaluation for accidental fire situation on the example of a steel beam

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SELECTED ASPECTS OF SAFETY EVALUATION FOR ACCIDENTAL FIRE SITUATION ON THE EXAMPLE OF A STEEL BEAM

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Probability-based approach:

$E_{fi,t}$ and $R_{fi,t}$

- random realisations of the reliable action effect and member resistance

Safety condition:

$$E_{fi,t} < R_{fi,t}$$

Failure:

$$E_{fi,t} \geq R_{fi,t}$$

Failure probability:

$$p_{f1} = \Pr\left(E_{fi,t} \geq R_{fi,t}\right)$$

Conventional standard approach:

$E_{fi,t,d}$ and $R_{fi,t,d}$

- ultimate acceptable values of $E_{fi,t}$ and $R_{fi,t}$

Safety condition:

Not only: $E_{fi,t,d} < R_{fi,t,d}$ but also:

$E_{fi,t} < E_{fi,t,d}$ and $R_{fi,t} > R_{fi,t,d}$

Failure probability:

$$p_{f2} = 1 - \Pr\left(E_{fi,t,d} < R_{fi,t,d} \cap E_{fi,t} < E_{fi,t,d} \cap R_{fi,t} > R_{fi,t,d}\right) = \\ = 1 - \Pr\left(E_{fi,t,d} < R_{fi,t,d}\right) \cdot \Pr\left(E_{fi,t} < E_{fi,t,d}\right) \cdot \Pr\left(R_{fi,t} > R_{fi,t,d}\right) > p_{f1}$$

Conclusion: $p_{f2} > p_{f1}$

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Global safety condition: $p_f < p_{f,ult} \Longrightarrow \beta > \beta_{req}$

Partial safety conditions:

- for action effect: $\beta_E = \alpha_E \beta > \beta_{E,req} = \alpha_E \beta_{req}$
- for member resistance: $\beta_R = \alpha_R \beta > \beta_{R,req} = \alpha_R \beta_{req}$

β_{req} depends on the reliability class (safety requirements) adopted to the analysis

range ⟷ moderate ⟷ minor ⟸ EN 1990

Fire resistance: The point in time when the failure occurs: $t_{fi} = t_{fi,d}$?

- This time value cannot be interpreted as the time of member destruction.
- This is a time value for which the member failure probability reaches the level no longer possible to accept.

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Example of a steel beam – basic safety measures:

Action effect:
- Beam is simply supported with the span length L
- Permanent load $g\,[\mathrm{kN/m}]$ and only one variable load $q\,[\mathrm{kN/m}]$, both uniformly distributed, are applied to the beam.

$$E_{fi,t,d} = \left(g_k + \gamma_Q \psi_2 q_k\right) L^2 / 8$$

g_k - characteristic value of permanent load

$\psi_2 q_k$ - quasi permanent value of variable load

The accidental design situation is considered.

- According to EN 1990 the constant value $\gamma_Q = 1{,}5$ should be adopted.

Member resistance:

- When steel temperature grows the steel yield point decreases as follows: $f_{y,\Theta} = k_{y,\Theta} f_{y,20}$

$$R_{fi,t,d} = R_{fi,t,k} / \gamma_{M,fi} = W k_{y,\Theta} f_{y,20}$$

- The constant value $\gamma_{M,fi} = 1{,}0$ should be adopted according to EN 1991-1-2.

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- Constant values of partial safety factors, $\gamma_Q = 1{,}5$ and $\gamma_{M,fi} = 1{,}0$, give the solution that the acceptable probability of downcrossing of the ultimate level $R_{fi,t,d}$ by the random value $R_{fi,t}$ is significantly greater than the acceptable probability of upcrossing of the level $E_{fi,t,d}$ by the random value $E_{fi,t}$. Such quantitative differentiation between the adopted internal safety requirements seems to be unjustified and unnecessary.

- A new, more accurate concept of the specification of partial safety factors, for action effect and for member resistance – separately, is proposed by the author. It is based on the regula of the split of global safety index β, given in the standard EN 1990 in which:

$\alpha_E = 0{,}7$ and $\alpha_R = 0{,}8$

- As a result we obtain the minimum values: $\gamma_{Q,\min} = \gamma_{Q,\min}(v_Q)$ and $\gamma_{M,fi,\min} = \gamma_{M,fi,\min}(\upsilon_R)$ for which the partial safety conditions are satisfied. They depend on the variability of the load q as well as on the variability of member resistance $R_{fi,t}$

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- Action q is a random variable described by means of Gumbel probability distribution.

$$G\left(\tilde{q}, u_Q\right) \Longrightarrow N\left(\bar{q}, \sigma_Q\right)$$

q_d from the condition $\beta_E = 0{,}7\beta > \beta_{E,req} = 0{,}7\beta_{req}$

q_k as a 95% upper fractile of q

$$\gamma_Q = \frac{q_d}{q_k} = \frac{1 - 0{,}78 v_Q \{0{,}577 + \ln[-\ln \Phi(0{,}7\beta)]\}}{1 + 1{,}867 v_Q}$$

- Member resistance $R_{fi,t}$ is the random value described by means of log-normal probability distribution

$$LN\left(\breve{R}_{fi,t}, \upsilon_R\right)$$

$R_{fi,t,d}$ from the condition $\beta_R = 0{,}8\beta > \beta_{R,req} = 0{,}8\beta_{req}$

$R_{fi,t,k}$ as a 95% lower fractile of $R_{fi,t}$

$$\gamma_{M,fi} = \frac{R_{fi,t,k}}{R_{fi,t,d}} = \frac{\breve{R}\exp(-1{,}645\upsilon_R)}{\breve{R}\exp(-0{,}8\beta\upsilon_R)} = \exp\left[(0{,}8\beta - 1{,}645)\upsilon_R\right]$$

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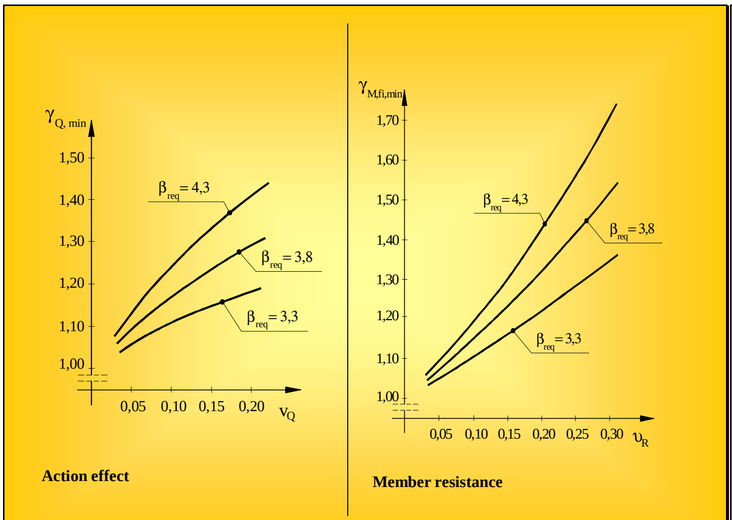
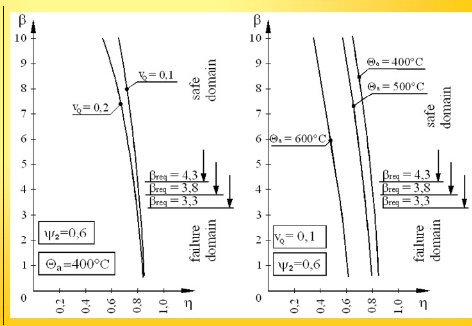


Analysis of beam safety level – exemplary solution:

$$g(\eta,\Theta_a,\beta_{req},\upsilon_R,\nu_G,\nu_Q)=R_{fi,k,t}-\left(\frac{g_k L^2}{8}\right)\left(1+\gamma_Q\psi_2\frac{\eta}{1-\eta}\right)=0$$

$$\eta = q_k/(g_k+q_k)$$



Conclusion:

- The value $\gamma_{M,fi} = 1{,}0$ suggested by the standard, is too small to secure the required safety level of the resistance. On the other hand, this drawback is partly compensated by the acceptance of constant value $\gamma_Q = 1{,}5$ higher than necessary. Furthermore, values of both partial safety factors, $\gamma_{M,fi}$ and γ_Q proposed to use in the case of fire, should be dependent on suitable coefficients of variation, υ_R and ν_Q in accordance with the relations shown in presented Figures.

Thank you for your attention.