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TIMBER STRUCTURES FIRE RESISTANCE

Abstract

The topic of this contribution is an outline of the timber structures design and assessment issues related to effects of fire according to standard and alternative (fully probabilistic) methods.

Keywords

Fire resistance, SBRA method.

Abstrakt

Předmětem tohoto příspěvku je nástin problematiky navrhování a posuzování dřevěných konstrukcí na účinky požáru dle normativních a alternativních (plně pravděpodobnostních) metod.

Klíčová slova

Požární odolnost, metoda SBRA.

1 INTRODUCTION

Affordability, construction speed, favourable physical-mechanical, ecological and aesthetical properties of wood are only some of the aspects why wood is more and more frequently used for the construction of new residential houses, e.g. timbered houses, log houses or sandwich-panel constructions as well as for refurbishment of current buildings and construction of penthouses, which are very frequently sought-after forms of housing.

First of all, mainly with roof structures, it is necessary that attention is paid to meeting all fire regulations and the correct design of wood elements as regards fire effects.

Currently, even other alternative methods, which are directly dependent on computer technology are developing in addition to the standard normative methods, thanks to computer technology development. They include, among others, the fully probabilistic methods (e.g. the SBRA method [5]).

2 WOOD EXPOSED TO FIRE EFFECTS

Wood elements exposed to fire and a temperature of about 300 °C flame up on their surfaces and in the beginning they burn relatively intensively. Step by step, a char layer occurs. The layer shows about 6 times better heat-insulation properties than grown timber (fig. 1).

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This layer then protects the residual cross-section area against intensive heating from the fire. The outer surface of the char layer has a temperature close to the temperature of the fire, and the inner surface of the char layer has temperature of about 300 °C. Under the char layer, there is a 35mm-thick heat-affected wood layer, whose strength properties and transformative properties are heat affected and decreased. A part of this layer, the one with a temperature of above 200°C, is called a pyrolysis layer as intensive thermal decomposition occurs there, which is connected with gas release and colour change as well as with weight loss. Humidity evaporates intensively from the layers whose temperature exceeds 100 °C. Under the pyrolysis layer, there is an almost unaffected residual cross-section, which shrinks during the fire.

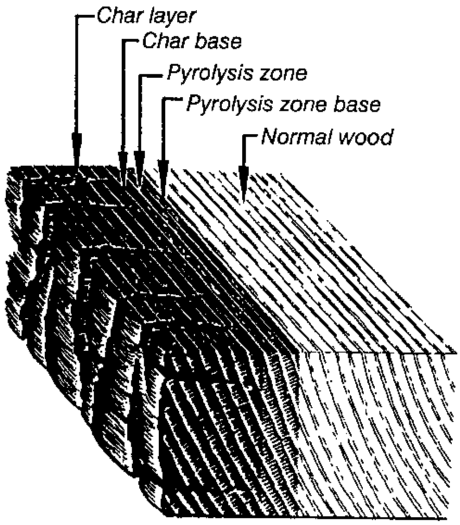

Fig.1: Wood cross-section exposed to fire effects

As to the residual cross-section, one can distinguish between subtle elements (usually the elements up to thickness of 80 mm are taken into account), in which the residual cross-section is almost zero even during short-time exposition to fire load, and massive elements, in which the residual cross-section is large enough to fulfil supporting functions even during the required time of fire resistance.

3 FIRE RESISTANCE ASSESSMENT ACCORDING TO EC5

Alternatively, three methods can be used for design and assessment of fire-exposed timber structure reliability according to the Eurocodes ([1] and [2]). They are a reduced cross-section method, reduced properties method, and a common method. These methods are ordered upward according to calculation demands and subsequently even according to the resultant fire resistance of the structure.

The principle of all these methods consists in cross-section charring depth calculation, or the change of physical and mechanical properties as well as the assessment of residual cross-section load-bearing capacity in the required fire resistance time.

Charring depth results from the design charring speed of the respective material and fire resistance.

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Design charring rate (ranges between 0.5 and 1.0 mm/min.) depends mainly on wood density or on the density of similarly-based materials (usually inversely proportional), and it is mentioned by means of a tabular characteristic value in ČSN EN 1995-1-2 ([2]).

4 SBRA-METHOD FIRE RESISTANCE ASSESSMENT

In the SBRA method, all random variables are represented by limited histograms, load-bearing capacities are expressed by duration curves and the respective histograms. Material properties are, opposed to EC5, expressed by limited histograms defined on the basis of laboratory tests (fig. 2 and 3) according to [3].

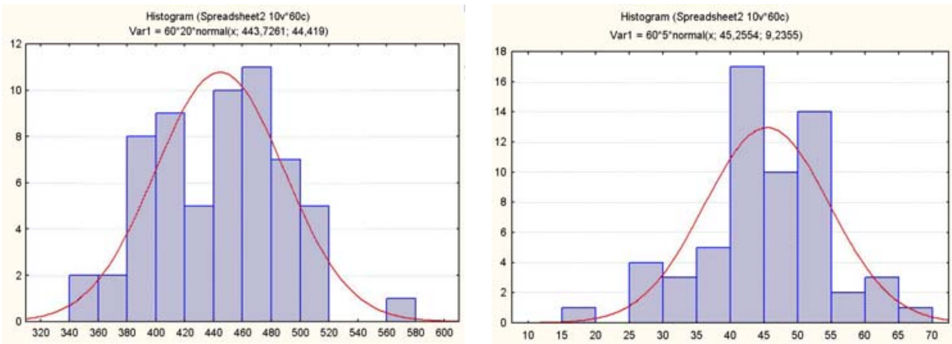

Fig. 2, 3: Histogram of density and bending strength of coniferous sawn wood according to [3]

The reliability function (FS) is analyzed by means of simulation technology and the direct method of Monte Carlo:

$$FS = R - S \tag{1}$$

where R is structural resistance, and S stands for a load combination effect.

5 AN EXAMPLE OF FLOOR JOIST LOAD-BEARING CAPACITY DURING FIRE

It is necessary to verify 60-minute-long fire resistance of 3.5-meter-long spruce floor joist (strength class S10) with an oblong cross-section (180/240 mm). The floor joist – a simple joist - is loaded with continuous uniformly distributed load (g_d = 3.0 kN/m´) and live load (p_d = 3.0 kN/m´).

5.1 Calculation According to EC5

The calculation was executed according to [2] by means of the reduced cross-section method.

A) Cross-Section Assessment

$$M_{fi,d} = \frac{1}{8} \, . \, (g_d + p_d) \, . \, L^2 = \frac{1}{8} \, . \, (3{,}0 + 3{,}0) \, . \, 3{,}5^2 = 9{,}19 \text{ kNm}$$

β = 0,8 mm/min

$d_{ef} = \beta_n \, . \, t + k_0 \, . \, d_0$

d_0 = 7 mm

k_0 = 1,0 (podle EC 5)

$d_{ef,60}$ = 0,8 . 60 + 1,0 . 7 = 55 mm

$b_{fi,60}$ = b – 2 . $d_{ef,60}$ = 180 – 2 . 55 = 70 mm

$h_{fi,60}$ = h – $d_{ef,60}$ = 240 – 55 = 185 mm

$$W_{fi} = \frac{b_{f,60} \,.\, h^2_{f,60}}{6} = \frac{70 \,.\, 185^2}{6} = 399\,292 \ \text{mm}^3$$

Design bending strength value

$$f_{m,fi,d} = k_{mod,fi} \,.\, k_{fi} \,.\, \frac{f_{m,k}}{\gamma_{M,fi}} = 1{,}0 \,.\, 1{,}25 \,.\, \frac{22}{1{,}0} = 27{,}5 \ \text{N/mm}^2$$

Design bending stress value

$$\sigma_{m,fi,d} = \frac{M_{fi,d}}{W_{fi}} = \frac{9{,}19 \,.\, 10^6}{399\,291} = 23{,}0 \ \text{N/mm}^2$$

Efficiency of utilization

23,0 / 27,5 = 0,84

B) Cross-Section Design

The width of the ***b*** joist calculated on the basis of reverse procedure of the joist fire resistance calculation assessment has been taken as the design value (b_{min} = 168.6 mm). The minimum width of the spruce joist (b_{min} = 168.6 mm) has been determined by means of the reduced cross-section method.

5.2 SBRA Method Calculation

The load-bearing capacity is determined by the limited histograms: permanent (dead) load (DEAD1) and live load (SHORT1). The density and the bending strength of spruce wood are also expressed by the limited histograms obtained from laboratory measuring.

The probability of fire breakout is supposed to be L/300. The decline in joist wood bending strength on the basis of load effective time is considered according to the "Madison Curve" – see the equation (2):

$$SL = 108{,}4\ T^{-0{,}04635} + 18{,}3 \text{ , where} \qquad (2)$$

SL … [%] is the relative current wood strength in the time T with respect to the short-term strength

T … is the duration of load combination effects [sec].

Mass burning rate (***β***) depending on wood density according to ([6]):

$$\beta = 0{,}4 + (280/\rho)^2, \qquad (3)$$

where

ρ … is the density of timber [kg/m³], The reliability function is analyzed in 10^6 simulation cycles. Structural resistance (R) is expressed by the wood bending strength reduced depending on the load duration (ranging from 0 to 50 years). The effect of load combination (S) is expressed by bending stress of the effective cross-section stressed by fire from three sides.

A) *Cross-Section Assessment*

The calculated probability of the respective spruce joist failure: $P_f = 0{,}000038$ (Fig. 4). This joist failure probability for 60-minute fire resistance corresponds to the common construction importance according to [6].

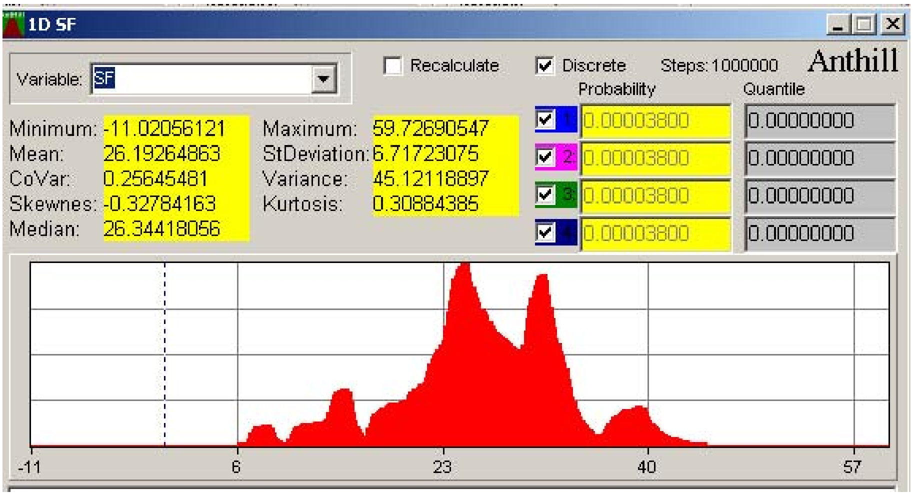

Fig. 4: The resultant histogram of the spruce joist reliability function

B) Cross-Section Design

The width of the *b* joist has been chosen as the design value. The width was set for the failure probability of the common construction importance $P_d = 0.00007$. The minimum possible width of the joist for 60-minute fire resistance is 173.6 mm for the spruce joist (fig. 5).

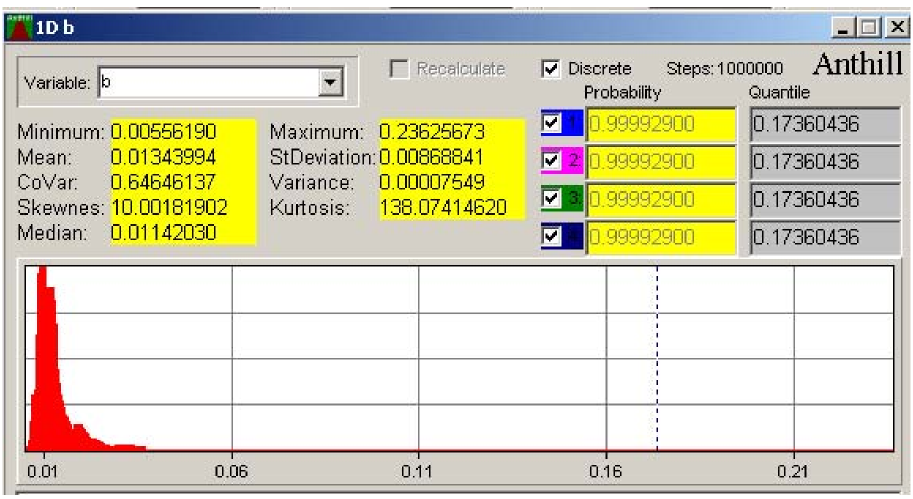

Fig. 5: The resultant histogram of the spruce joist minimum width

6 CONCLUSION

Table no. 1 shows the comparison between the results of the design and the assessment of the floor joist by means of the SBRA method and according to EC5.

Tab. 1: Comparison of results according to the SBRA method and the calculation according to EC5

	Assessment		Design	
	EC5 Efficiency of utilization	SBRA probability of failure	EC5 (Minimal width of the beam – *b* [mm])	SBRA (Minimal width of the beam – *b* [mm])
Spruce	0,84	0,000038	168,6	173,6

It follows from the table no. 1 that the results of both the methods are comparable. The advantages of the SBRA method include the possibility of expressing the failure probability for bearing elements and joints, the possibility of expressing the load-bearing capacity, physical and mechanical as well as geometrical properties of elements by means of limited histograms. The SBRA method also allows including the probability of fire breakup into the calculation, effects of humidity, density and other factors influencing fire resistance of elements and joints in timber structures.

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