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SELECTED ASPECTS OF FAILURE PROBABILITY ASSESSMENT FOR FIRE SITUATION

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To reliably calibrate suitable partial safety factors, useful for the specification of global condition describing structural safety level in considered design case, usually the evaluation of adequate failure probability is necessary. In accidental fire situation, not only probability of the collapse of load-bearing structure, but also another probability related to the people staying in a building at the moment of fire occurence should be assessed. Those values are different one from another in qualitative sense but they are coupled because they are determined by similar factors. The first one is the conditional probability with the condition that fire has already occured, whereas the second is the probability of failure in case of a potential fire, which can take place in the examined building compartment, but its ignition has not yet appeared. An engineering approach to estimate such both probabilities is presented and widely discussed in the article.

Key words: reliability, safety measures, failure probability, safety analysis, network diagram.

1. Introduction

Failure probability p_f is usually adopted as a basic and objective safety measure when the classical safety analysis is performed, for the case of unexpected event potentiality, danger to some people or building structure. Application of such measure explicitly determines the understanding of the limit state. The limit state is not reached exactly at the point-in-time when the considered event really takes place, but earlier, when the probability of its occurrence may not be accepted. Conclusively, the limit state condition is in general formulated as follows:

$$p_f \leqslant p_{f,ult}. \tag{1.1}$$

This formula is commonly rearranged to the equivalent inequality:

$$\beta \geqslant \beta_{req} \tag{1.2}$$

in which β is the global reliability index. Its required (target) value β_{req} is unequivocally connected with ultimate acceptable value of failure probability (i.e. $p_{f,ult}$). For example,

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if the considered random variables (in general they are interpreted as reliable action effect E, and appropriate resistance R corresponding with such effect) are described by means of normal or log-normal probability distribution, then:

$$p_{f,ult} = \Phi(-\beta_{req}) \rightarrow \beta_{req} = -inv\Phi(p_{f,ult}) \tag{1.3}$$

Symbol $\Phi()$ means here the cumulative distribution function (cdf) of standardized normal probability distribution. It is the so-called the *Laplace* function, easy to find in ordinary statistical tables. Notation $inv\Phi$ is understood as an inverse function of Φ.

Probability $p_{f,ult}$ can be definitely determined only if corresponding reference period $n[years]$ is given. Ussualy it is assumed that $n = 50 years$; however, $n = 1 year$ is also considered in many cases. In general, if probability $p_{f,ult}$ identified with the period equal $n = 50 years$ is known, then its respective value, adequate for $n \neq 50 years$, may be calculated from the equation:

$$\Phi(\beta_{50}) = 1 - \Phi(-\beta_{50}) = \Phi(\beta_n)^{50/n} \tag{1.4}$$

hence if $n = 1 year$ we have:

$$\Phi(\beta_1)^{50} = \Phi(\beta_{50}) \tag{1.5}$$

Values of β_{req} (or equivalently $p_{f,ult}$) are differentiated by experts or suitable authorities, dependently on the assumed safety requirements. Such methodology leads to the specification of various kinds of reliability classes RC. They are most frequently related to the consequences of failure or to the relative cost of a safety measure. Exemplary values of $\beta_{1,req}$ (related to one-year reference period) and associated with them target failure rates $p_{1,f,ult}$, defined for ultimate limit state, are given by JCSS [1] (Table 1).

Table 1

Target values of $\beta_{1,req}$ and corresponding probabilities $p_{1,f,ult}$ according to JCSS [1].
Wymagane wartości $\beta_{1,req}$ i odpowiadające im prawdopodobieństwa $p_{1,f,ult}$ według JCSS [1]

Relative cost of safety measure	**Consequences of failure**		
	minor	**moderate**	**range**
large	$\beta_{1,req} = 3,1$ $(p_{1,f,ult} \approx 10^{-3})$	$\beta_{1,req} = 3,3$ $(p_{1,f,ult} \approx 5 \cdot 10^{-4})$	$\beta_{1,req} = 3,7$ $(p_{1,f,ult} \approx 10^{-4})$
normal	$\beta_{1,req} = 3,7$ $(p_{1,f,ult} \approx 10^{-4})$	$\beta_{1,req} = 4,2$ $(p_{1,f,ult} \approx 10^{-5})$	$\beta_{1,req} = 4,4$ $(p_{1,f,ult} \approx 5 \cdot 10^{-6})$
small	$\beta_{1,req} = 4,2$ $(p_{1,f,ult} \approx 10^{-5})$	$\beta_{1,req} = 4,4$ $(p_{1,f,ult} \approx 5 \cdot 10^{-6})$	$\beta_{1,req} = 4,7$ $(p_{1,f,ult} \approx 10^{-6})$

Classification presented in this table is not compatible with the recommendations taken from EN 1990 [2]. In the European standard, only three reliability classes are specified – for range, moderate, and minor safety requirements. Furthermore, not only values of $\beta_{1,req}$ but also of $\beta_{50,req}$ (defined for 50-year reference period) are shown there (Table 2). Let us notice that safety requirements specified in the Eurocode are significantly stronger in quantitative sense in relation to the analogous assignments proposed by JCSS.

Table 2

Reliability classes according to EN 1990 [2].
Klasy niezawodności według EN 1990 [2]

Reliability class	**Safety requirements**	β_{req} **for reference period equal:**	
		one year	**50 years**
RC3	range	$\beta_{1,req} = 5,2$ $\left(p_{1,f,ult} \approx 9,9 \cdot 10^{-8}\right)$	$\beta_{50,req} = 4,3$ $\left(p_{50,f,ult} \approx 8,5 \cdot 10^{-6}\right)$
RC2	moderate	$\beta_{1,req} = 4,7$ $\left(p_{1,f,ult} \approx 1,3 \cdot 10^{-6}\right)$	$\beta_{50,req} = 3,8$ $\left(p_{50,f,ult} \approx 7,2 \cdot 10^{-5}\right)$
RC1	minor	$\beta_{1,req} = 4,2$ $\left(p_{1,f,ult} \approx 1.3 \cdot 10^{-5}\right)$	$\beta_{50,req} = 3,3$ $\left(p_{50,f,ult} \approx 4,8 \cdot 10^{-4}\right)$

2. PROBLEM WITH INTERPRETATION

Values of $p_{f,ult}$, linked with the right side of Eq. (1.1), are assigned arbitrarily, to be adequate for the assumed reliability class. Regarding the case of fully developed fire, it should be stated that designing based on such regulations, when differentiated reliability classes are taken into consideration, allows to select the parameters of necessary fire protection measures in a more rational and economic way. More detailed presentation of the design technique useful to be applied in this field is the aim of many articles (for example [3], [4]). In the present paper some aspects of the assessment of probability p_f, associated with the left side of Eq. (1.1), are discussed. Those values generally depend on a great amount of factors, connected between each other in a complex and intercorrelated network. Consequently, the complicated analysis is then needful. However, in the case of fire, the internal structure and connection hierarchy of such network seems to be quite typical, so that basic mathematical model can be sufficient to competently evaluate the value which is looked for.

At the beginning we have to precisely define what kind of probability is considered. It is extremely important because at least two interpretations can be distinguished, different one from another, not only from quantitative but also from qualitative point of view. They are as follows [5], [6]:

- probability of failure, caused by fire if it is known that fire ignition has occurred and; moreover, this fire has reached the flashover point (it may be described as a fully developed fire) – in further analysis such probability will be marked by symbol p_f,

- probability of failure, caused by fire which can take place; however, it has not yet occurred (so the designer has no information about its ignition and flashover) – let us appoint symbol p_{ff} for its designation.

Relation between p_f and p_{ff} is given by *Lie* [7]:

$$p_{ff} = p_t p_f \tag{2.1}$$

where p_t means the probability of fire occurrence (not only of fire ignition but also of reaching the flashover point). As we can see, probability p_f should be interpreted as a conditional probability with the condition that fire has occurred, and the temperature of exhaust gas in the whole compartment is uniform (the fire is fully developed). Not only qualitative but also quantitative distinction between probabilities p_f and p_{ff} seems to be very significant. Even if conditional probability p_f is large, probability p_{ff} is usually quite small and does not seem to be apprehensive, because in reality the value of probability p_t is also slight [5], [8].

However, quantity p_{ff} sometimes can also be interpreted as a conditional probability. Both values, p_f and p_{ff}, allow the designer to evaluate the real safety level, but with the assumption that she/he knows that failure will occur resolutely as a result of the fire action. Meanwhile, the construction can be destroyed also in a situation when fire has not appeared at all. If the probability of such event is described as p_{f0}, then finally, the probability of construction collapse generated as a result of whichever possible reason p_{fff} can be calculated as:

$$p_{fff} = (1 - p_t)\, p_{f0} + p_t p_f \tag{2.2}$$

Eq. (2.2) follows directly from the scheme of *Bernoulli* sampling with two samples.

Despite of the fact that the time duration of fire is always marked as a cutting line stretched on time axis, it is very short in relation to the whole period of the human lifetime and also to the period of building exploitation. Moreover, this is the accidental event, which should take place very rarely. For this reason the fire case can be treated as a point-in-time episode, which is the approach helpful for the evaluation of the probability p_t. Owing to such simplification, the frequency of fire occurrence may be analysed basing on the well known formalism of the *Poisson* process. Probability p_t is then understood as the probability that fire occurres at least once in the considered time T (the most frequently this is the whole time of the building use, but sometimes only one year of its exploitation is taken into account). Consequently, the probability that fire occurs x times during time period T is:

$$p_x(x) = \frac{(\lambda T)^x\, e^{-\lambda T}}{x!}, \quad x = 1, 2, ..., \infty. \tag{2.3}$$

where parameter λ is usually called the proces intensity. Application of such formula leads to the following evaluations of probability p_x, and finally probabilityp_t:

- probability that fire has not occurred at all in time T:

$$p_x\,(x = 0) = e^{-\lambda T} \tag{2.4}$$

- probability that fire has occurred exactly once in time T:

$$p_x\,(x = 1) = \lambda T e^{-\lambda T} \tag{2.5}$$

- probability that fire has occurred at least once in time T (i.e. once or more than once):

$$p_x\,(x \geqslant 1) = 1 - p_x\,(x = 0) = 1 - e^{-\lambda T} = p_t \tag{2.6}$$

The evaluation of intensity λ, specified for buildings with only one type of fire compartment was given by *Lie* [7]:

$$\lambda = hA \tag{2.7}$$

where $h\left[m^{-2}\right]$ means the risk of fire ignition (calculated per $1m^2$ of fire compartment), $A\left[m^2\right]$ is the area of fire compartment. In the cases when many kinds of fire compartments, with various sizes attributed to each of them, can be separated in the considered building, the genaralized assessment proposed by *Burros* [9] may be applied:

$$\lambda = h\overline{A} = h\frac{A_F}{N} \tag{2.8}$$

in which A_F is the total area of all compartments in the whole building; whereas N is the number of such compartments. Concluding, $\overline{A}$ is the mean value of the area of single fire compartment specified in the considered building.

In general $x << 1$, therefore the following simplification is acceptable and commonly used:

$$p_x\,(x \geqslant 1) = 1 - e^{-\lambda T} = 1 - e^{-h\overline{A}T} \approx h\overline{A}T = p_t \tag{2.9}$$

Suitable values of risk h are estimated by many authors for various types of the utility of fire compartments. They are easy to find in a professional literature. The author wants to pay particular attention to the article prepared by *Ryden* and *Rychlik* [10] in which the methodology of the assessment of probability p_t is discussed when only incomplete input data are approachable.

3. Relation between failure probability and event sequence

Let us assume that failure (F) is a result of the following event sequence:

$$E1 \rightarrow E2 \rightarrow E3 \Rightarrow F \tag{3.1}$$

where particular symbols denote succeeding episodes:

$E1$ – fire has started (fire ignition has occurred),

$E2$ – fire reached the flashover point (temperature of exhaust gas can be treated as uniform in the whole fire compartment),

$E3$ – fire caused failure.

Consequently, we can say that failure will happen only if all episodes take place: $E1$ AND $E2$ AND $E3$. Such statement seemingly leads to simple equation useful for the evaluation of failure probability $p_{ff} = P(F)$ as a product of component probabilities:

$$p_{ff} = P(F) = P(E1) \cdot P(E2) \cdot P(E3) \tag{3.2}$$

This formula is still frequently recommended for application in classical safety analysis for fire situation (for example in [11]). However, it would give the reliable assessments of $P(F)$ only if the considered events were independent in statistical sense. Furthermore, it is also important that the order of the occurrence of particular events cannot be arbitrary, since it is explicitly determined. Hence the essential conclusion should be underlined in presented study that probabilities $P(E2)$ and $P(E3)$ from Eq. (3.2) have to be interpreted as conditional ones: $P(E2/E1)$ and $P(E3/(E1 \cap E2))$, respectively. As a result of such deliberation the more clear and also more correct notation of Eq. (3.2) is postulated by the author:

$$p_{ff} = P(F) = P(E1 \cap E2 \cap E3) = P(E1) \cdot P(E2/E1) \cdot P(E3/(E1 \cap E2)) \tag{3.3}$$

In reality, the analysed event sequence, described by means of Eq. (3.1), is not the only one possible to happen under typical fire conditions. For instance the flashover point has not to be reached; moreover, the structural member failure not always takes place. The probability of such eventualities should also be taken into consideration. In consequence there is a necessity to further complicate the structure of Eq. (3.3). Let $\overline{E}$ denotes the event contrary to event E. It is also the event complementary to E in mathematical sense, so that $P(E_i) \cup P\left(\overline{E}_i\right) = 1$. Finally, the event sequence, leading to the failure, may be presented by means of the logical tree (Fig. 1) [5].

Application of complementary events gives the opportunity to use the well known formalism of complete probabilty. Consequently:

$$P(F) = \sum_{i=1}^{n} P(F/E_i) P(E_i) \tag{3.4}$$

hence:

$$P(F) = P(F/E1)\,P(E1) + P\left(F/\overline{E1}\right)P\left(\overline{E1}\right) \tag{3.5}$$

where:

$$P(F/E1) = P(F/E2)\,P(E2/E1) + P\left(F/\overline{E2}\right)P\left(\overline{E2}/E1\right) \tag{3.6}$$

and further:

$$P(F/E2) = P(F/E3)\,P\left[E3/(E2 \cap E1)\right] + P\left(F/\overline{E3}\right)P\left[\overline{E3}/(E2 \cap E1)\right] \tag{3.7}$$

A slightly different interpretation of the formalism presented above is given by *Holicky* and *Schleich* in [12].

The logical tree shown in Fig. 1 can be further developed and complicated, the most frequently through the addition of the next subsequent levels to its internal structure. Let us notice that in such a case the previously evaluated value of failure probability will change. Therefore, if we want to increase the precision of the probability assessment, and for that reason we take into account in the next step some additional factors influencing the fire safety, then we can easily obtain a value even significantly different from the previous one. Therefore, the maximum attention should be paid when using such calculation methodology.

Safer for the implementation, and owing to that more user friendly, seems to be an approach proposed by *Fitzgerald* [13]. While applying this technique, the scheme in Fig. 1 has not to be enlarged when more precise analysis of its internal levels is necessary. It is sufficient to create a special separate network diagram, associated with a particular level of the logical tree presented above.

Let us now discuss in detail the simplest way to accurately estimate the value of probability $P(E2/E1)$ given in Eq. (3.3). According to the *Fitzgerald's* suggestion, the interpretation of such event will now be noticed in a slightly different way; however, quite similar in relation to the main purpose of the presented evaluation methodology. Instead of the analysis whether the considered fire will reach the flashover point or not, another study, investigating the probability that this fire will not be extinguished, is undertaken. The condition that an ignition of fire has already occurred, and the designer knows that it has been started in an examined compartment, remains unchanged.

As we stated before, a failure means in this analysis that fire will not be extinguished at all. Only three ways of its extinction are specified as possible in real conditions:

- $e1$ – fire will burn out spontaneously,
- $e2$ – fire will be extinguished owing to working of active fire protection measures (sprinklers, water curtains etc.), without any activity of a fire brigade,
- $e3$ – fire will be extinguished due to the activity of a fire brigade.

The considered ways of fire extinction have to be understood as independent in the statistical sense. For this reason, the possible event that fire is only partially supressed by

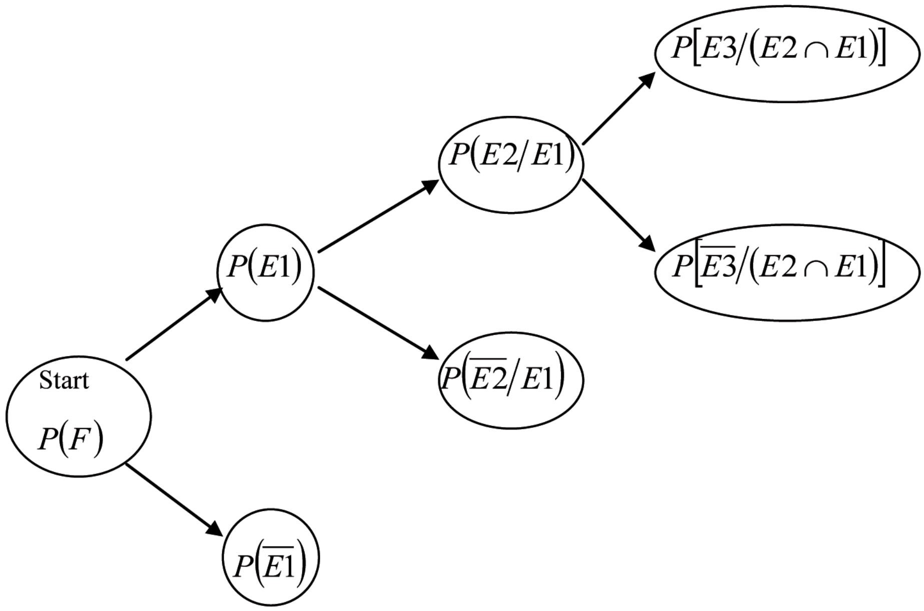

Fig. 1. Logical tree proposed for the evaluation of probability $P(F)$ when the formalism of complete probability is used.
Rys. 1. Drzewo logiczne proponowane do szacowania prawdopodobieństwa $P(F)$ przy użyciu formalizmu prawdopodobieństwa zupełnego

active fire protection measures, but definitively extinguished only when the fire brigade firefighting action is successfully finished, should be classified explicitly as the $e3$ manner. Moreover, all three considered ways are complementary in relation to manners $\overline{e1}$, $\overline{e2}$ and $\overline{e3}$, respectively. Finally, the following evaluations can be performed:

- fire which has started will not be extiguished at all if event $\overline{e1}$ AND event $\overline{e2}$ AND also event $\overline{e3}$ occur, so failure probability $P(F)$ can be assessed by the formula:

$$P(F) = P\left(\overline{e1}\right) \cdot P\left(\overline{e2}\right) \cdot P\left(\overline{e3}\right) = [1 - P(e1)] \cdot [1 - P(e2)] \cdot [1 - P(e3)] \quad (3.8)$$

- fire which has started will be extinguished as a result EITHER of the occurrence of event $e1$, OR event $e2$, OR event $e3$. Occurrence of only one from those three events is sufficient to cause the extinction of failure. The detailed way of the assessment of probability $P\left(\overline{F}\right)$ is presented in Fig. 2. In conclusion the final formula applied for its calculation has the form:

$$\begin{aligned} P\left(\overline{F}\right) &= P(e1) + P\left(\overline{e1}\right)P(e2) + P\left(\overline{e1}\right)P\left(\overline{e2}\right)P(e3) = \\ &= P(e1) + [1 - P(e1)]\,P(e2) + [1 - P(e1)] \cdot [1 - P(e2)]\,P(e3) \end{aligned} \quad (3.9)$$

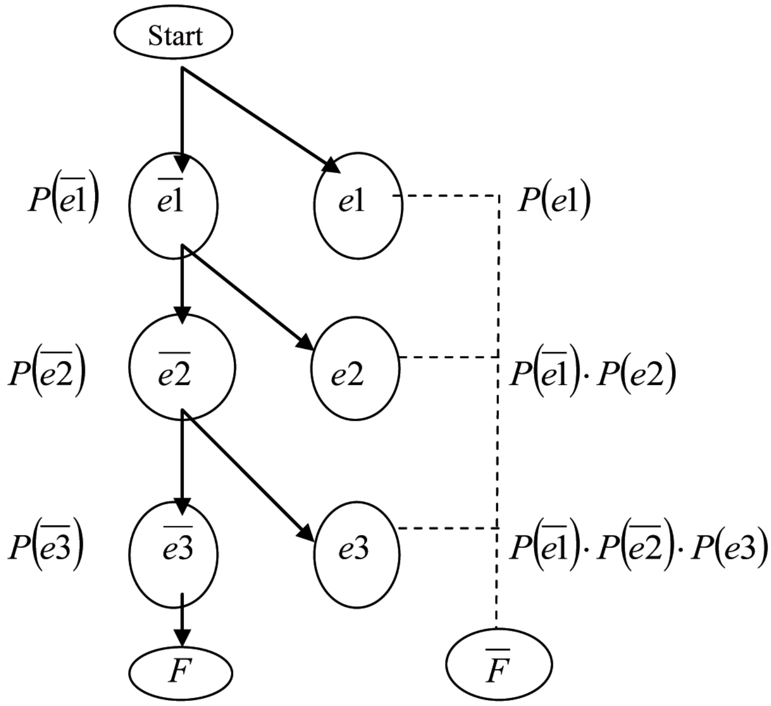

Fig. 2. Network diagram, proposed by *Fitzgerald* [13], helpful for the estimation of failure probability in case of fire limited to one fire compartment.
Rys. 2. Diagram sieciowy zaproponowany przez *Fitzgeralda* [13], pomocny w szacowaniu prawdopodobieństwa zawodu w przypadku pożaru ograniczonego do pojedynczej strefy pożarowej

The network diagram, proposed by *Fitzgerald*, helpful for such evaluation methodology is shown in Fig. 2. Let us notice that all connections marked with the solid line are always linked with AND logical gate, which is synonymous with the conjunction of independent events. Probability $P(F)$ is in such case calculated as a simple product of component probabilities (see Eq. (3.8)). On the other hand, connections drawn by means of the broken line can be identified with OR logical gate, and as a conclusion with the alternative of considered events. This is the reason why in this part of the diagram probability $P\left(\overline{F}\right)$ is estimated as an ordinary sum of component probabilities (see Eq. (3.9)). Additional advantage of such calculation technique is the fact that the final result of the evaluation does not depend on the order of occurrence of particular component events. Correctness of the obtained solution may be verified by checking the following equation:

$$P(F) = 1 - P\left(\overline{F}\right) \tag{3.10}$$

The scheme presented below is associated with fire limited to only one separate fire compartment. If it is possible that such fire may expand from one fire compartment to adjoining one, then the demonstrated diagram should be extended by the addition of the next level of the analysis. Detailed procedure of calculation in such case is given in [13].

4. Failure probability and standard design approach

In the particular case of fire, if thermally induced deformations have not to be limited by a separate condition, the failure of a structural element is explicitly connected with a point-in-time t_{fi} when reliable action effect $E_{fi,t}$ reaches the level specified by member resistance $R_{fi,t}$, suitably reduced at high temperature. Such conclusive value of the action effect is usually identified with the occurrence of unfavourable combination of external loads applied to the structure, together with internal forces and moments generated as a consequence of thermal strains constrainment. Both quantities, $E_{fi,t}$ and $R_{fi,t}$, should always be treated as random variables, if all possible fire cases are considered in one analysis. Finally, member failure probability p_{f1} can be calculated from the following formula:

$$p_{f1} = P\left(E_{fi,t} \geqslant R_{fi,t}\right) \tag{4.1}$$

In the classical, semi – probabilistic standard approach to evaluation of structural safety level, two ultimate values of basic random variables are specified. The first one is the design value of action effect $E_{fi,t,d}$, whereas the second – the design value of member resistance $R_{fi,t,d}$. Global safety condition $E_{fi,t} < R_{fi,t}$ is then replaced by another one, formulated as $E_{fi,t,d} < R_{fi,t,d}$; however, two independent inequalities should formally be added. Consequently, it can be presented in the complex form:

$$E_{fi,t,d} < R_{fi,t,d} \text{ and } E_{fi,t} < E_{fi,t,d} \text{ and } R_{fi,t} > R_{fi,t,d} \tag{4.2}$$

Probability $p_{f2} \neq p_{f1}$ is now the measure of failure threat. Its value is determined as follows:

$$\begin{aligned} p_{f2} &= 1 - P\left(E_{fi,t,d} < R_{fi,t,d} \cap E_{fi,t} < E_{fi,t,d} \cap R_{fi,t} > R_{fi,t,d}\right) = \\ &= 1 - P\left(E_{fi,t,d} < R_{fi,t,d}\right) \cdot P\left(E_{fi,t} < E_{fi,t,d}\right) \cdot P\left(R_{fi,t} > R_{fi,t,d}\right) > p_{f1} \end{aligned} \tag{4.3}$$

It is well known that the value of p_{f2} is always greater than p_{f1}. This means that such simplified methodology of the assessment of member safety level gives evaluations, which are safe in general, but frequently overestimated and uneconomical. It is important that failure is now defined in a different way. Let us consider the case when the particular action effect $E_{fi,t}$ is greater than ultimate value $E_{fi,t,d}$; however, simultaneously member resistance $R_{fi,t}$ remains sufficiently high, so $E_{fi,t} < R_{fi,t}$. It is obvious that the analysed member under such circumstances still can carry applied loads, according to Eq. (4.1); nevertheless, in the light of Eqs. (4.2) and (4.3) member failure is indicated. Similar conclusion will be drawn for the situation when member resistance $R_{fi,t}$ is already too low $\left(R_{fi,t} < R_{fi,t,d}\right)$ but the accompanying action effect is at the same time small enough, then $E_{fi,t} < R_{fi,t}$.

Both the value of unfavourable action effect and the level of member carrying capacity depend on the fire moment or, more generally, on the fire characteristics. The resistance of the structural element always decreases if steel temperature rises, because of the material yield point reduction. The reliable action effect most often increases under such circumstances; however, its conclusive value can remain constant during the whole fire time, if only any restraints are imposed on thermal deformations. Neither load changes generated by evacuation of building occupants nor the reduction of loads as a result of furnishings combustion are taken into consideration in the analysis. The natural consequence of such dependence is the fact that both design values, $E_{fi,t,d}$ and $R_{fi,t,d}$, are suitable functions of fire time t_{fi}.

The fire resistance limit state occurs in the point-in-time, described as $t_{fi,d}$, when the design value of the action effect $E_{fi,t,d}\left(t_{fi,d}\right)$ reaches the level specified by the design value of member carrying capacity $R_{fi,t,d}\left(t_{fi,d}\right)$. However, it is not always necessary because much earlier the random value of such effect can be too high $\left(E_{fi,t} \geqslant E_{fi,t,d}\right)$, or random member resistance may not remain high enough $\left(R_{fi,t} \leqslant R_{fi,t,d}\right)$. It is significantly important that fire moment $t_{fi} = t_{fi,d}$ cannot be interpreted directly as the time of a member destruction. It is only the time value for which the member failure probability reaches the level no longer possible to accept. Moreover, downcrossing of the level $R_{fi,t,d}$ by random value R_{fi} is not formally permitted; however, such event can, extremely rarely, occur and the maximum acceptable probability of its occurrence must be defined. Similarly, also the upcrossing of the level $E_{fi,t,d}$ by the random value of $E_{fi,t}$, at any fire time t_{fi}, is possible; nevertheless, the acceptable probability of such event must be fixed as minimal.

As we can see, the quantitative specification of both ultimate values; $E_{fi,t,d}$ and $R_{fi,t,d}$, is explicitly connected with the adoption of the acceptable level of failure probability. Discussion presented above leads to the conclusion that its value should be fixed suitably softer if the standard, semi-probabilistic design technique is applied in the analysis, in relation to analogous settlement, specific for the situation when fully probabilistic approach is used. In other words, we have to accept that $p_{f2,ult} > p_{f1,ult}$ if we want to keep the same safety requirements. Such formal distinction is simply the consequence of slightly different interpretation of a limit state.

Assignation of the ultimate levels, determined by considered values $E_{fi,t,d}$ and $R_{fi,t,d}$, should be based on reasonable and well-founded arguments. In [4] the author postulates that the acceptable probability of upcrossing of the ultimate level, marked by the design value $E_{fi,t,d}$, by the random value of the action effect $E_{fi,t}$, should be quantitatively similar to the acceptable probability of downcrossing of the ultimate level $R_{fi,t,d}$ by the random value of member resistance $R_{fi,t}$. The results obtained in this way seem to be more rational and better justified than the analogous ones taken from the classical analysis proposed by standard EN 1990 [2]. On the example of simple steel beam [4] the author proved that the value of partial safety factor specified for member carrying capacity and suggested by the standard [2], i.e. $\gamma_{M,fi} = 1,0$, is too small to secure the required safety level of the resistance. On the other hand, this drawback could be partly compensated by the acceptance of a constant value of partial safety factor defined especially for variable loads, i.e. $\gamma_Q = 1,5$, higher than necessary. However, it is essential to underline that in clasical safety analysis, adapted directly to accidental design situations and basing on the rules taken from [2], specification the lesser value of this factor, i.e. $\gamma_Q = 1,0$, is recommended. Furthermore, values of both partial safety factors, $\gamma_{M,fi}$ and γ_Q, proposed to use in the case of fire, should depend on suitable coefficients of variation, υ_R (if log-normal probability distribution is adopted for characterisation of random member resistance) and ν_Q (for normal probability distribution taken for the analysis of random variable load) respectively.

5. Conclusions

The basic purpose of this paper is giving more accurate interpretation of the idea of failure probability, related to the accidental design situation when fully developed fire takes place in the considered building compartment. It is well known that precise evaluation of such safety measure is necessary to correctly specify the limit state condition, not only in the case of the analysis of potential exceptional an unfavourable events, but also in classical safety assessment when persistant action combination is taken into account. The value of failure probability is directly used for such calculation if fully probabilistic design approach is applied. However, in engineering practice most frequently the safety checking deals with only simplified semi-probabilistic evaluating technique in which the partial safety factors are adopted as suitable safety measures. Nevertheless, also in this case the estimation of their conclusive values is uneqivocally determined by adequate quantities, probability of upcrossing of the acceptable limit of action effect (i.e. $E_{fi,t,d}$), and probability of downcrossing of the admissible level of member resistance (i.e. $R_{fi,t,d}$).

The real value of failure probability $P(F)$, resulting from more or less complex safety analysis, has to be compared with maximum, possible to accept, value of $P_{ult}(F)$ which depends on the appropriate safety requirements. Suitable levels of such limitations imposed on the considered probability are given in many documents and standards, for example in the form of the so called reliability classes (RC). In the present article it is shown that safety requirements adopted to the analysis are significantly stronger if semi-probabilistic design approach, postulated by many standards, is used, in relation to requirements taken into account in the case of the application of fully probabilistic design methodology. The reason is different formulation of a limit state condition. Therefore, suitably higher value of $P_{ult}(F)$ can be then admitted if the preservation of similar safety level is desirable.

The interpretation of searched probability should be clearly and uneqivocally defined. In clasical structural safety analysis probability p_f, which is conditional, with the condition that fire has already ocurred, is usually estimated. However, in many cases we want to evaluate the failure probability related to some people, for example to building occupants who will be able to inhabit in considered compartment if fire ignition and flashover takes place, or even to firemen taking part in firefighting action. In such context probability p_{ff}, understood in a different way than the previous one (see Eq. 2.1), is usually estimated. In general some kinds of network diagrams and/or the formalism of complete probability concept are then used.

Particular events considered in the analysis generate the event sequence, which is the base of given fire scenario. Even if all those events have to occur in order to failure, the probability of its occurrence cannot be evaluated as a simple product of component probabilities. It is essential to realize that the events, taken into account in such study, are not independent in statistical sense. Moreover, the order of their occurrence is of a great importance.

In professional literature (for instance in [14]) the mixed approach is very often suggested to application, when the product of only a few component probabilities is additionally multiplicated by many deterministic factors, expressing the influence of various potential circumstances such as: accesible active fire protection measures, possibility of the automatic fire detection, qualifications and competence of fire brigade etc. The main advantage of such evaluation technique is its simplicity; however, it is not fully correct in relation to some theoretical foundations. Very promising in this field seems to be implementation of the concept of *Bayesian* networks (developed for instance by *Holicky* and *Schleich* [12]) and/or using the formalism taken from the analysis of the so called *Markov* chains. More detailed description and discussion of such methodologies of safety assessment for fire situation goes beyond the limits of the present article.

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WYBRANE PROBLEMY SZACOWANIA PRAWDOPODOBIEŃSTWA ZAWODU W SYTUACJI POŻARU

Streszczenie

W artykule podjęto próbę doprecyzowania interpretacji prawdopodobieństwa zawodu szacowanego w odniesieniu do wyjątkowej sytuacji projektowej pożaru rozwiniętego. Rozważa się dwa rodzaje prawdopodobieństw. Są one różne zarówno w sensie jakościowym jak i ilościowym. Niemniej jednak w analizie powinny być traktowane jako sprzężone, ich wartość determinują bowiem te same czynniki. Pierwszą z badanych wielkości jest warunkowe prawdopodobieństwo zawodu przy warunku że pożar został zainicjowany i rozgorzał. Drugie prawdopodobieństwo odnosi się do potencjalnego pożaru, który może zaistnieć w określonej strefie pożarowej ale jak dotąd jego zainicjowanie nie miało miejsca. Prawdopodobieństwa omawiane w pracy kojarzy się zwykle z odmiennymi celami badawczymi. Pierwsze z nich wykorzystywane jest głównie w klasycznej analizie bezpieczeństwa konstrukcji, drugie natomiast stosuje się do oceny ryzyka towarzyszącego użytkownikom budynku jeśli przebywają wewnątrz w chwili rozgorzenia ognia, a także w celu oszacowania stopnia zagrożenia ekip gaśniczych podejmujących walkę z pożarem.

Aby w sposób wiarygodny oszacować wartości poszukiwanych prawdopodobieństw należy posłużyć się odpowiednim modelem obliczeniowym, w szczególności opartym na analizie pewnego typu diagramu sieciowego. Alternatywnym rozwiązaniem dyskutowanym w pracy jest wykorzystanie koncepcji prawdopodobieństwa zupełnego. W prezentowanym artykule zamieszczono przykłady praktycznego zastosowania podejść proponowanych przez autora. W jego końcowej części uzyskane oszacowania prawdopodobieństwa zawodu odnosi się do normowej metody stanów granicznych wykorzystującej półprobabilistyczny format obliczeń. Przeciwstawia się ją obliczeniom w pełni probabilistycznym wskazując na istotne różnice formalne i wykazując konieczność innej specyfikacji globalnego warunku bezpieczeństwa.

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