Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 11 (1980)

Artikel: Safety concepts for fire protection

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DOI: https://doi.org/10.5169/seals-11399

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Safety Concepts for Fire Protection

Concepts de sécurité pour la protection contre l'incendie

Sicherheitskonzepte für den Brandschutz

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SUMMARY
A safety concept for fire protection is outlined focussing on measures eligible for a limited exchange with respect to the effort employed. Special consideration is given to the interaction between measures influencing the occurrence of fires and structural measures, such as member design and the arrangement of fire compartments. In regard of this interaction the allocation of effort can be adjusted according to national circumstances, types of buildings considered, and individual circumstances.

RESUME
Un concept de sécurité pour la protection contre l'incendie est présenté, soulignant en particulier les mesures essentielles. L'attention est attirée sur l'interaction entre des mesures agissant sur l'apparition des incendies et des mesures structurelles, tels que le dimensionnement des éléments de construction et l'arrangement des parties-coupe-feu. Cette interaction permet de déterminer l'effort principal en fonction des circonstances nationales, des types des bâtiments et de leur utilisation, et selon les circonstances individuelles.

ZUSAMMENFASSUNG
Ein Sicherheitskonzept für den Brandschutz wird vorgestellt, wobei jene Massnahmen im Vordergrund stehen, bei denen eine gewisse Ausgleichsmöglichkeit im Hinblick auf den jeweiligen Aufwand besteht. Insbesondere wird die Wechselwirkung zwischen Massnahmen, die das Auftreten von Bränden bestimmen und baulichen Massnahmen, wie die Bemessung von Bauteilen und die Bildung von Brandabschnitten, verfolgt. In Anbetracht dieser Wechselwirkung kann die Verteilung des Aufwandes auf die jeweiligen Massnahmen je nach nationalen Gegebenheiten, Art und Nutzung der Gebäude und nach den Gegebenheiten im Einzelfall erfolgen.

1. INTRODUCTION

Various measures are employed to protect human lives, buildings, and contents of buildings against hazards arising from fire. Within a specified set of measures providing an agreeable level of fire safety individual conditions should be accounted for by allowing a limited exchange of effort with respect to various measures. The conditions governing a reasonable - or optimal - effort may vary considerably as in the case of industrial buildings. However, an exchange of effort must be confined to measures with strong interaction averting the same cause or consequences of hazards.

This safety concept - presented in a slightly extended form in this contribution-provides the background for the model code draft "Structural Fire Protection"/1/ which introduces a design concept making allowance for a limited exchange between structural measures and measures influencing the occurrence of fires.

2. OCCURRENCE OF FIRES

In the first place measures concentrate on the prevention of fires. The expected number of fires $E(N_o)$ per year in a specified population of buildings of the same type, use, and floor area A_o will obviously depend on the effort invested in preventive measures. Generally, the probability of occurrence of at least one fire per year within the area A_o can be estimated from

$$p_o \cong E(N_o) \qquad (1a)$$

assuming the occurrence of fires in time to follow a poisson distribution /1/. According to studies on office buildings /2/ the number of fires is approximately proportional to the floor area confirming a poisson modelling for the spacial occurrence as well /3/, /4/. Hence, the probability of occurrence of fires per year within an area $A = k\ A_o$ may be assessed by:

$$p_k \cong k\ p_o \qquad (1b)$$

Given the occurrence of fire, merely a limitation of spread - or losses - remains subject to influence.

3. FIRE FIGHTING MEASURES

Considering buildings of the same general arrangement and spacial distribution of the potential fire load the fire process is governed primarily by the fire fighting measures applied. Uncontrolled fires processes within this population will vary only with respect to unavoidable deviations from the same target conditions and the random location of the fire origin.

Let the random fire process be represented by a single appropriate characteristic X (e.g. maximum gas temperature during the process or total area seized by fire) which in the individual case takes the value max x_o for an uncontrolled process and otherwise some value $x < \max x$, depending on the success of fire fighting measures. $s = x/\max x$ is referred to as the individual "fire extent" allocating a realization of the random extent S to every fire event.

The distribution function of the extent S reflects the effort invested in fire fighting measures (e.g. public fire brigades, private fire brigades, sprinkler-systems) or more precisely, their efficacy which is frequently limited by insufficient water supply. In case of general dispense of all measures every initial fire would grow out of control yielding the maximum extent (s=1) as the almost sure event (see fig. 1, $F_o(s)$). If, on the other hand, the effort in fighting fires would tend to infinity the extent of initial fires would rarely be exceeded. Eventually, according to the measures employed, the distribution $F_m(s)$ for a specified effort will be located between these limiting distributions (see fig. 1). As the distribution $F_m(s)$ describes the probability for an initial fire to develop up to a certain extent, the reverse distribution $\bar{F}_m(s)=1-F_m(s)$ may be regarded as the probability that fire fighting measures fail to a certain extent in limiting fire spread.

The probability for complete failure of measures $\bar{F}_m(1) = p(\bigcap_i \{\text{failure of measure } i\})$ entailing an uncontrolled fire process in the wake of a flash-over may be approximately calculated from /1/, /5/:

$$\bar{F}_m(1) = p_{f_m} = \prod_i p_{f_{mi}} \tag{2}$$

wherein $p_{f_{mi}}$ denotes the probability that control is not established by public fires brigades ($p_{f_{m1}}$), nor by private brigades ($p_{f_{m2}}$), nor by sprinkler-systems ($p_{f_{m3}}$), etc. Possible dependency between these events as in the case of insufficient water supply may be accounted for by introducing a lower bound for p_{f_m}.

Considering the probability of occurrence of (initial) fires p_o or p_k according to equ. (1), the probability of occurrence of fires per year with an extent exceeding s amounts to

$$p_s = k\, p_o\, \bar{F}_m(s) \tag{3}$$

provided that the efficacy of the fire fighting measures is independent of the size $A = k\, A_o$ of the floor area. This independency may hold for one-storied-(industrial) buildings, for multiple-storied-buildings, however, the efficacy may decrease. According to /1/, /5/ a decrease by $k = A\,/\,A_o$ (with A_o the average floor or compartment area in types of multiple-storied-buildings considered) may be assumed when assessing fires following complete failure of measures yielding the following probabilities for uncontrolled fires:

$$\begin{aligned} p_{s,1} &= k\, p_o\, \bar{F}_m(1) && \text{for one-storied-buildings} \\ p_{s,1} &= k^2 p_o\, \bar{F}_m(1) && \text{for multiple-storied-buildings} \end{aligned} \tag{4}$$

4. STRUCTURAL MEASURES

The general arrangement of a building with respect to possible operations of the fire brigades, spread of fire, etc. - which, however, was supposed to remain unchanged within the population considered - may significantly influence the extent of fire in terms of $F_m(s)$.

Furthermore, structural measures comprise arrangement of the structural system and design of members such as to provide sufficient structural integrity, i.e. to sustain exposure to fire with adequate reliability. This adequate reliability may be derived from the acceptable failure probability for structural members in non-accidental situations considering the probability of occurrence of fires (accidental situation). As structural members are mainly affected by fires of a great extent it generally suffices to consider fires yielding the maximum extent, i.e. uncontrolled fires. Thus, the conditional failure probability

$$p_{fb} = \frac{p_f}{p_{s,1}} = \frac{p_f}{k^{(2)} p_o\, p_{f_m}} \qquad \text{for } p_f < p_{s,1} \tag{5}$$

is decisive for the design encountering this accidental situation. The design procedure then involves assessment of either the complete uncontrolled fire process as a stochastic process /5/, /6/, or in simplification, assessment of a single random characteristic max X_o representing the uncontrolled fire process, e.g. the equivalent fire duration /5/, /7/.

Obviously, member design becomes superfluous as the probability of occurrence of fires approaches the acceptable failure probability p_f ($p_{fb} \rightarrow 1$). This result eventually reflects common sense - if great effort is employed to avoid a hazardous situation further effort applying to the situation should diminish.

Another structural measure is the partitioning of buildings into fire compartments size A_i ($A = \sum_n A_i = k\ A_o$). Guidelines for acceptable sizes A_i for one-storied-(industrial)buildings may be derived from fire fighting criteria, taking the available water supply into account /8/. Additional criteria can be introduced by loss considerations as follows.

If the characteristic X, representing a fire process, is chosen to describe losses in case of a fire instead of a physical quantity, then s would attribute the relative losses - as compared to the maximum losses possible - to the individual fire event. For simplicity only losses from contents of buildings are accounted for supposing an equal distribution of monetary value throughout the floor area A.

The expected relative losses in buildings without partitioning would amount to

$$E\ (S) = \int_o^1 k\ p_o\ f_m\ (s)\ s\ ds = k\ p_o\ \overline{S} \tag{6a}$$

with $p_k = k\ p_o$ the probability of occurrence according to equ. (1b), $f_m(s)$ the density function of relative losses and $\overline{S}$ the expected losses in case of a fire (conditioned by the occurrence of fires).

Fire effective partitioning into n compartments - neglecting the probability that members separating compartments fail to fulfill their function - reduces the maximum losses possible by 1/n. Thus, the expected relative losses in buildings with a total floor area A divided into n equal-sized compartments decrease to

$$E\ (S_n) = \int_o^{1/n} k\ p_o\ f_m\ (s)\ s\ ds\ /\ F\ (1/n) = k\ p_o\ \overline{S}_n \tag{6b}$$

with $\overline{S}$ the expected loss in case of fires; however, considering only relative losses up to 1/n.

In case of fire fighting effort tending to infinity partitioning remains without effect with respect to the expected losses since the losses approach zero regardless of size of floor area. If fire fighting measures were generally omitted the expected relative losses would decrease from ($k\ p_o$) to approximately

$$E_o\ (S_n) = k\ p_o\ /\ n \tag{6c}$$

These boundary considerations allow the following conclusions: Are fire fighting measures so efficient that without partitioning the expected losses in case of fire are much smaller than maximum losses possible within a compartment ($\overline{S} \ll 1/n$), then partitioning does not contribute considerably to a decrease of losses. If, however, the expected losses without partitioning exceed the maximum losses possible within a compartment ($\overline{S} > 1/n$), then partitioning, surely, is an effective measure for limiting losses. Eventually, this measure deserves even more attention if conditions governing losses (monetary values, probability of occurrence p_o, etc.) vary considerably within a building.

It should also be noted that, in case of effective partitioning, member design does not have to account for the probability of occurrence within the whole floor area A but only within the compartment size A_i. This increases the conditional failure probability according to equ.(5) by n when introducing the probability for uncontrolled fires as $p_{s,1} = k\ p_o\ p_{f_m} / n$. Hence, with respect to member design, partitioning may also be regarded as a measure directed at reduction of the probability for uncontrolled fires, as members are only affected by fires occurring in the respective compartment area. When assessing structural members or elements separating fire compartments, consequently, both adjacent areas have to be considered.

5. CONCLUSIONS

Measures directed at preventing fires and fighting fires, as well as member design, and partitioning of building into fire compartments form a subset of measures eligible for an exchange of effort employed. Individual optimization, however, may be restricted by public safety requirements. It should be acceptable, e.g. to refrain from severe requirements applying to the fire resistance of structural members in case of extensive fire fighting measures or preventive precautions. On the other hand, structural measures may not replace a minimum standard in fire fighting, e.g. substituting a missing water supply. Nevertheless, with a safety concept of this kind sufficient degrees of freedom are available for establishing subsets of measures adjusted to prevailing individual conditions.

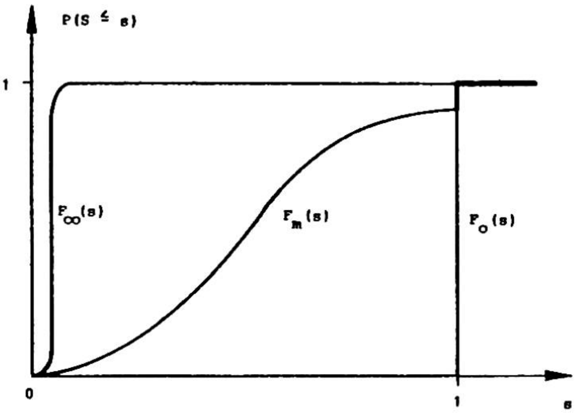

Fig. 1

Possible distribution functions of the random fire extent S for different effort employed in fire fighting measures

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