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ENHANCING THE SAFETY OF HIGH RISK BUILDINGS THROUGH THE CONCEPT OF LEVELS OF SAFETY AND USE OF FIRE ENGINEERING TOOL: THE NEEDS OF INTERNATIONAL COOPERATION

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Abstract

The document presents the reflections of a working group of limited duration, convened by the author after the attacks on the World Trade Center (WTC). The resulting fire has shown the limits of the current concept of safety for addressing premises presenting a very high density of risks. It has stressed the need to use the more specific and multidimensional concept of "level of safety", corresponding to various risk factors and assessed through fire engineering tools. The design of important buildings could also in the future be influenced by the decision of the owner to address scenarios of malevolence or by requirements from public authorities to prevent dangerous interactions between buildings in case of fire. Other ways of progress concern such different themes as the evacuation of people, the resistance to fire of structural assemblies under violent fires, and the control of the total calorific load present in a building.

Keywords: Fire safety engineering, level of safety, concentration of risks, interaction, evacuation, calorific load.

1. Introduction

After the intense emotion caused by the drama of the World Trade Center (WTC) or that, in 1999, of the Tunnel of Mont-Blanc, engineers in the various countries, start to rethink on the needs regulations evolvement or progress of knowledge that reflects the relevance that such events dictate. In the case of WTC, the remarkable public report produced by FEMA and ASCE (1) considerably helped to facilitate findings and evaluation. In France such reflections have been undertaken over a limited period of time in 2002 as discussed in this paper. Rather than answers and conclusions, it defines tracks for possible actions and needs for international cooperation.

Currently, we are faced with more and more events which presented large deviations from those addressed by the regulations. For example fire regulations do not explicitly take into account the probabilistic nature of events. Hence calling for a development of the fire safety engineering (FSE) approach.

A second matter of concern seriously in discussion is the attention paid by authorities on constructions presenting high risks, which apart from tall buildings includes large commercial facilities, underground constructions, road and railway tunnels; all of which share the same safety problem as tall building.

Also, as far as safety is concerned, common observation seemed to suggest that the level of safety should be related given risk. To the usual risk factors originating from natural phenomena, technical incidents or human errors, risks linked to malevolence must be considered from now on. Should these risks be integrated in the rules building design.

The WTC events and Mont Blanc Tunnel, both suggests the necessity of more developments on research and testing for the two pillars of fire safety, which are evacuation of people and fire resistance of structures. Additionally, the aggressiveness of fire attacks raises question on the contribution of thermal effects (especially in the case of fully developed fires) not only of the interior finishes of buildings but also its contents (linked to its activities) in which little is known nor regulated.
The aim of this paper is to develop and discuss each of these preceding remarks and to see how answers can be brought to them through regulations, research and standardisations conducted at national and international levels.

2. The Input of Fire Safety Engineering

In Europe, the general requirements for fire safety in buildings are formulated by the European Union (Directive on constructions products). These requirements are as those commonly adopted by most countries:

In the event of fire outbreak it is assumed that:

- the load-bearing capacity of the construction can last for a specific period of time,
- the generation and spread of fire and smoke within the works are limited,
- the spread of fire to neighbouring construction works is limited,
- occupants can leave the works or be rescued by other means,
- the safety of rescue teams is taken into consideration.

The general method of compliance with the requirements is not fundamentally different in the prescriptive approach from that of the engineering approach (Fig.1) except that in the former, the safety strategies and the performance required are set according to the types and uses of buildings.

![Fig. 1 Prescriptive approach vs Engineering approach](image)

Prescriptive regulations, based on fire scenarios are dictated by experience and, relatively well fulfil their aim, i.e. the safety of people. Each year, there are several hundreds of fatalities of fire in France, whereas road fatalities are counted in thousands. Although the inflexible character of the prescriptive regulation is often underlined, the door is generally open to derogations. The authorization relies on the advice of a group of experts and often on tests, ensuring that, through a different strategy and performance, the initial requirement of safety is satisfied "at the same level".

On the other hand catastrophes implying very large fires draw the limits of the prescriptive approach. The approach does not provide a methodological frame addressing specific fire scenarios. It does not either define a method to address the economic aspects of fire risks.

These methods are provided by the fire safety engineering. As it is the case for structural safety, the approach uses the concept of level of safety (which is a "distance" between the current situation and the undesired one) and refers to limit states and critical situations. For example, the level of safety concerning the evacuation of people can be expressed by the margin between the time required for
evacuation and the time when the level of temperature or the height of the smoke layer under the ceiling will create a critical situation. Both time period are stochastic variables and according to their respective distributions, the level of safety will be expressed with a certain level of confidence.

The engineering approach gives more freedom (and responsibility) to designers. It also allows a better understanding of critical situations and risks not only for the design of new buildings, but also for the operation of existing buildings. Since the existing stock of buildings present a large on stake on fire safety in countries where the renewal is slow, the progress on Fire Safety Engineering will not only benefit to new and exceptional buildings but also to the existing stock.

If the scientific bases of the probability approach are well established, as described for instance by Frantzich (2), its integral applications to real cases still requires much effort. An accumulation of statistical data is needed concerning the probability of outbreaks of fires of different types, reliability and efficacy of the systems, human behaviour, etc.

The difficulty to get a complete method should not prevent Fire Safety Engineering to gain a status within the building codes. Sweden and several other countries have taken decisions for that, and the awareness of Fire Safety Engineering among designers in these countries will foster more progress. The availability of a model code, as it is envisaged by the Benefeu project in the European Union (3), could promote a political decision in countries which still hesitate. The importance of the tasks requires both regional approaches, such as the Benefeu project, and the integration of the results in an international cooperation, through the studies of CIB and the standardization works conducted at ISO.

3. A Specific Approach for Areas Presenting a High Concentration of Risks

Many large cities in the world present areas where the height and density of buildings, the number of people, and the intricacy of underground constructions and facilities, create a large concentration of risks. The WTC catastrophe has displayed the consequences of that interdependence between buildings. The fire and collapse of the Twin Towers caused a partial or total ruin of eight neighbouring buildings. The collapse or severe damages were induced by the fall of burning debris. The "domino effect" which is extremely feared in the case of industrials risks, occurred here markedly but, fortunately, without additional consequences in terms of human lives.

Despite of its importance, the issues of fire in buildings does not seem to call for changes in the regulations. The risks involving high rise building do not seem larger than with existing ancient buildings in historical centres of European cities.

Other types of interactions between buildings appear growing and deserve consideration:

- The influence of the fire plume on the ventilation inlets of neighbouring buildings,
- In the case of underground facilities linking between them, consideration should be given to the propagation of smoke and ensuing risks of panic. Such layout is frequent with metro tunnels and underground stations linking with shopping centers, without the possibility of fire breaks.

The evaluation approach of such risks cannot be performed building by building, but at the initiative of the owners themselves. The assessment of risks linked to interactions and the coordination of procedures in the case of fire depend on the public authority which permits new construction.

An exchange of information on how such problems may be addressed in different countries, through studies and procedures, could be organized in an international framework such as CIB.

4. Managing Risks Linked to Malevolence

The attacks on the World Trade Center constitute a scenario that no designer, concerned with safety as he might be, would have considered. That fire will remain hopefully an extreme case. But it raises questions on how to address, in the design of major scale construction works; scenarios that upset the basic principles of fire safety. Such scenarios are linked in particular to malevolence: fire, explosion, chemical and bacteriological weapons.
Fire safety of tall buildings relies on fire compartments (normally in one floor) and staged evacuation where only the occupants of the affected level be transferred to an assigned level. In the case of WTC, the impacts and fires struck several floors, destroying the emergency egress of the higher levels and forcing evacuation of the other floors. As already mentioned, it would be unrealistic to try to design buildings against such actions. However would appear advisable to prevent more "ordinary" malevolence by taking adequate measures when designing buildings; safety measures during operation being a separate issue.

The objective is not to make it easy for potential to malevolent acts, through identifying and adequately protecting sensitive spots and also to avoid scenarios of malevolence, to evolve towards catastrophe.

Such concern has to be taken seriously with tall buildings, large public facilities and public works (tunnels, bridges). It requires the designer (or another designer) to cast a new look at the project, to assess the vulnerability of its features although it seems difficult to turn it into a mandatory requirement. Preventing actions of malevolence through appropriate design concept would rather result from a voluntary decision by the building owner in which the public authority could help by providing methodological tools.

The reflections on these subjects in different countries, if leading to concrete conclusions, may be followed by standardization works on appropriate methods to be used.

5. Renewed Attention

Frequently, the interactions occurring during a fire involved four essential factors: the building with its geometrical, chemical and structural characteristics; active protection of systems; the occupants and the various products; and equipment present in the premises in association with the activities carried out. Two parameters which play a very important role is the nature of the fire start and the intervention of firefighters.

![Fire Start Diagram](image)

Fig. 2 Fire safety – The global system

The characteristic of WTC fires is that two of the above-mentioned parameters of fire safety did not play their usual part because of the instantaneous nature and extensive scale of initial fire: the active protection system should they not have been destroyed, the sprinklers would not have been effective and the action of the firefighters which nevertheless had significantly assist with the evacuation of occupants. These onwards, safety rests upon three basic parameters: human evacuation, fire resistance of the building and total calorific local present in the premises.
The same observation can be made for the recent tunnel fires in Europe, which were accidental. Even if there may have been some errors in the operation of the safety ventilation system in the case of Mont Blanc Tunnel, still no difference can be noticed with two other cases (Tauern in Austria and Gothard in Switzerland) where quick and violent fires could not be brought under control and ending up, with more than twenty fatalities. Hence, safety then relies totally on the three above-mentioned parameters.

Now do these factors relate to the WTC tragedy?

5.1 Evacuation of People

Under the circumstances of large and fast fire, speedy evacuation of occupant is priority. Its implementations depends on human reactions as well as the availability and capacity of means of escape.

The WTC tragedy onfirmed the importance of human behaviour, as highlighted by a study came out in England [4]. The FEMA report outlined the positive role played by the evacuation exercises conducted in the period preceding the drama. The reaction time of people is largely improved by such training. Moreover the right decisions taken by the trained occupants of the building favourably influence the reactions of the visitors present in the premises, since people tend to reproduce the response, useful or passive, of those sharing the same situation.

Regarding the ways of egress, the importance of photoluminescent paint and provision of emergency lighting in the stairways have been highlighted. On the other hand the proximity of the various stairways has appeared an undesirable feature in the case of an act of destruction. The requirement, present in several building codes, such as the French codes indicated that the minimal distance between the two main compulsory egress stairways, seems to originate from walking distance considerations, and this will probably be reinforced to ensure the greatest possible independency between them.

5.2 Fire Resistance of Structures

The FEMA report provides a precise analysis of the probable scenario of collapse of the World Trade Centre towers. It also underlines the needs for research and experiments on two subjects:

- the behaviour of fireproofing coatings on steel elements under various mechanical actions,
- the resistance to fire of structural assemblies, such as those of floors and columns, under violent fire.

In France where tall buildings are frequently made with reinforced concrete structures, the same need for research on structural assemblies is felt. Moreover the use of high performance concrete for towers as well as for tunnels, thus allowing thinner structures; creates an important need of research on a key parameter, i.e. the speed of spalling of concrete under fire.

5.3 Controlling the Calorific Load Present in the Building

As in most countries, precise requirements are laid down in France by regulations concerning the reaction of fire to interior lining materials, in various building categories. Moreover a certain requirement (regarding ignition) exists for fixing furniture in certain premises, for example armchairs in picture houses. However, only towers are subjected to a requirement expressed in terms of total calorific load present per square meter of floor.

The two points highlighted above are important measures of controlling fire in building and these will be described in greater detailed below.

5.3.1 Fire Reactions on interior living materials

The conventional fire scenarios used for fire resistance also applies to fire reactions. The strength of the thermal attack induces a behaviour which may differs in terms of rate of heat release. Through Fire Safety Engineering approach, fire data is required which allow prediction of the material behaviour under the conditions of real fire and good correlations are obtained with cone calorimeter[5].
For engineering purposes the expectation would be to derive that prediction from the mandatory information on reaction of fire for accompanying products put on the market.

In that respect, the single burning item (SBI) test adopted in Europe is promising and its use for Fire Safety Engineering purposes should be extended. The test submits large samples of materials or products to severe thermal flow produced by a sand burner and the vertical configuration of the samples in a corner. One of the main parameters measured by that test, the FIGRA (fire growth rate) presents a good correlation with the time to flashover measured at the ISO room corner test.

5.3.2 The Calorific Load Linked to the Activity.

The fire of Mont Blanc Tunnel has shown that a considerable amount of thermal energy was released by the fire from a truck with its load of margarine. Such a calorific load corresponded to the normal use of the tunnel and the fire was not malicious. Of course, it was not the case of only kerosene for WTC. But the fire was also fed with combustible matters coming from furniture and associated activities. Their total calorific load which is unknown, has necessarily increased the intensity and duration of the fire and may have contributed to the collapse of the towers.

In large shopping centers sheltered in complex buildings, large calorific loads, example due to winter sports clothes, may be present, without any information available on their ability of ignition, unit calorific load and smoke production capacity. It is not unreasonable to think that such data could be required by the consumers. The availability of a certain amount of information in that field would fill a gap for a correct application of the FSE approach.

Actions which would Fire Safety Engineering go far beyond the field of building is required in order to progress discussion on these subjects. It concerns cables for electricity and computer networks, which are present in growing quantities in the plenums of office buildings (and also in metro tunnels, for multiple uses). In the case of a fire, the insulating materials of such cables may create a secondary fireplace with an important generation of heat and smoke. Due to the electricity which circulates in them, these cables may also initiate the start of fire, and when they are in important arrays in ventilated voids, they may propagate fire for long distances. Cables are not considered construction products by the European Union, although they are permanently installed in the buildings and often stay in place when new cables are installed.

Safety would be increased by an adequate test of fire reactions of these cables and demanding regulations concerning their presence in important buildings.

Conclusions

Following the WTC tragedy actions are both required in the field of prevention and in building design to address fire risks of uncommon dimension. Regarding prevention, it would be up to the owner to address malevolence risks through building design features. The public authorities are concerned with the management of areas with high concentration risks, where the interactions with a new construction could involve specific studies and requirements. Prevention also requires better control of the calorific load of products and equipment present in the building in relation to the activities. The improvement of the response of the buildings concerns the evacuation system and fire resistance of structural assemblies.

Progress in these various fields goes through the development of Fire Safety Engineering, the esplication of the levels of safety and the emergence of a probabilistic approach. FSE should gain recognition in the building codes, at least for partial use. There is still a considerable need for developing new concepts, improving models, and accumulating statistical data on characteristic values. For that an important effort of international cooperation is necessary through programs of research, exchange of information within organizations such as CIB, and standardization works pursued within ISO.
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