

FIRE SAFETY ENGINEERING

Modern engineering design is based on the application of scientific research and engineering principles, using calculations, measurements, empiricism and judgement. Nowadays for most techniques these calculation methods have been finalised so far and are ready for use by user-friendly computer programs so that every designer can give a personal interpretation of the requirements or rules.

1. INTRODUCTION

Formerly it was not so and a simplified and often uniform solution was proposed resulting in the univocal rules, focused on the simplest solutions that were then extrapolated to larger models. This is called prescriptive or required rules. Today this results in a double negative effect :

- On the one hand we do not know whether these extrapolations are still acceptable for the newest technical evolutions of buildings, materials and users domains.
- On the other hand a large part of the actual research is not applied to new concepts, where they could possible bring about savings without harming the required comfort and security level.

Whilst with pure science it is necessary to come as close as possible to the truth, for designs or applied science it is important to find an adequate solution for a problem, contributing towards the exigencies or conditions.

This solution thus is subjective and open for evaluation. Good solution models give power to the expected positive judgement. The chosen solution is thus not the answer to the posed problem.

If this manner of approach - to performance or required performances - is recognised, it will also be easier for the non-designers to accept these actions.

Let's now consider how for fire safety the problem solving thinking has been displaced from pure prescriptive to purpose aimed, from prescriptive to performing. We start our story in 1666.

After the large fire in London (which lasted 5 days and put 2/3 of the city in ashes) new regulations were made for the construction of houses :

- stone instead of wood ;
- the thickness of the walls was prescribed ;
- the size of the building in function of the width of the street.

In this we recognise 3 important sizes that are important in case of fire :

- reaction to fire ;
- resistance against fire ;
- exposure to radiation.

As far as resistance to fire is concerned they started from empirical tests on known materials, first on a random basis, later with the use of a standard oven and later by the calculation of the strength on the basis of the physical properties of the material (f.i. steel).

2 unknown facts still remained : the resistance of a structure is different than for one single element and what if the fire becomes larger than the standard test fire.

A favourable "fire-resistant" material has following qualities :

- it is difficult to ignite ;
- it prevents the spread of the fire ;
- it does not add fuel to the fire;
- smoke and toxic gases are limited to a minimum.

Internationally the empirical classifications that are assigned still are very different. They consider less the smoke production of the materials than the 3 other criteria. A uniform scientific determination of inflammability of materials is in research.

Radiation heat of a fire on an adjacent building can be calculated and thus a safe distance can be determined. In the actual legislation this is empirically translated in a standard minimum distance or the exigency of having an Rf wall. This largely limits the architectural freedom.

It is clear : "Fire is a dynamic data" whereas structures are fixed. The last years a lot of research has been done with regard to the evolution of a fire, the destructive power of it and the determination of the point to which a construction can resist a determined fire intensity.

Considering the different parameters (time, fuel, ventilation, ...) a "design fire" is determined. Hereby the flashover or the transition to a fully developed fire is an important target. Nowadays many models are available to determine a "design fire" in pre-flashover phase. Temperature, radiation, smoke development, speed of extension can accurately be calculated. For more complex spaces there is a switch to CFD (computational fluid dynamics) : the computer works with the ending element method with the interaction between (mostly) 10.000 to 1.000.000 fields.

A quadratic or exponential growing fire (expressed in heat capacity = kW) is mostly the result and is used as "design fire". Stationary fires are seldom and this only if fuel is limited to a well known extent. Working with stationary fires mostly results in overdimensioning of structures and safety installations. From the side of the insurers this is nevertheless an acceptable point of view.

After the flashover the fire is no longer determined by the fuel but by the ventilation, meaning the existing or forced opening to the outer air determine the intensity and duration of the fire. The mass of the structure and its thermal characteristics also become important. Has a fire wall of 4 hours been calculated on the internal pressure ?

Active fire protection means, such as detection, automatic extinguishing and smoke extraction are today an integrated part of fire safety although it is seldom used in the actual legislation and earlier it was principally imposed by the insurers. The principal objective of these means is to avoid that the post-flashover situation occurs. Today the choice of the elements used can also be determined in a more precise manner and the RTI (response time index) can be focused on the design fire and the necessary quantity of the means of extinguishing can be determined. Heat and smoke extraction has a triple objective : keep free the evacuation routes, remove hot smoky gases and facilitate the entrance for the fire services. Furthermore many of the modern materials are lost because of the (corrosive) smoke, and then the advantage is clear. In this case uniform solutions can not be offered. Each time the geometry of the building and the expected smoke production must be reconsidered.

The evacuation of persons from a building on fire is not an easy thing. The provision of escape routes and stairs is not always as judicious as possible. The presence of disabled persons, the gathering at doors, not using the closest stairway are "bottlenecks" in a traditional execution where distance is THE criterion. Visualised programs that can make ample simulations are available. Using these indicates a professional approach of the security aspect in large complexes.

The evolution to a project bounded approach and according to design methods calculated approach of the fire security problem has started some time ago as it already was for instance for structure and techniques. To gain the trust of authorities and fire services, a trust in the assumed design methods and in the users of them is necessary. Abroad a lot of work is done with regard to descriptive and purpose aimed standards, Belgium may not miss the boat either.

The statement of the Ministry of Internal Affairs, through Mr Froeyman, in this regard offers good perspectives.

2. RESEARCH

In order to increase the mentioned confidence in FSE a certain number of bottlenecks have to be further investigated :

1. A lack of design purposes

The objective of a design always consists in reaching a certain result, f.i. enable a certain construction or reach a desired comfort temperature. For fire safety these objectives are not clear, which level of security is wanted and how can we quantify this uniformly ?

2. Resistance to alterations

The actual prescriptive rules, that can sometimes lead to crazy circumstances, have one large advantage : what has to happen is written black on white and this offers an easy solution for the users of them. It is much more difficult to determine first the required security and to evaluate or control the design with its calculation models afterwards.

3. Training

Further to the previous point it can be put that less training has to be passed through to apply little rules than to execute calculations, to design to a certain exigency. Specialised courses are developing now (f.i. Leeds, Edimburg, Greenwich and Belfast). It is to be expected that some larger architect and engineering offices will have some of their engineers following this training so that this knowledge can be used in their building designs.

4. Transmission of knowledge and technology

FSE methods should not only be available to designers and controlling instances, they should also be easy to use and to evaluate. Research reports cannot be used in practice. They have to be translated in "manuals" to reach a quick result in a concrete situation.

5. Legal bottlenecks

The juridical responsibility of the designer towards the end result is known. The resulting cobjectives for damage can be very important, even if there is no human harm. Nor the designer, nor the controlling instance will fall back on calculations that have not been justified by test experiments and full scale tests.

On the other hand, juridical, one has to be informed of the latest techniques so that "the best" or "the safest" design can be delivered.

6. Administrative bottlenecks

To "officially" provide new regulations, texts, standards or manuals required much time. For months, years technical commissions and working groups prepare a text and only after a period of remarks and amendments it can be put in an official text.

The recently fast evolution in FSE results in 2 problems : designers use methods that are not yet officially established, authorities only want to consolidate in a text of law or standard the things that have been proved right.

7. Scientific basis

Fundamental research in specialised centres and universities provides the basis on which applications can be built. The destructive character of fire makes this research expensive and it is not without risks. Nowadays not all the parameters are for a 100 % quantifiable so that applied research and technical developments sometimes do “free wheel” a little. Today some come forward with a product or method that is commercially well looking and that gives a fast result whilst the contents mostly is a blackbox : input and output are known but what happens in between ?

To solve these bottlenecks and to give FSE a full place between the other building techniques, research is done on different places and within different organisations, fundamentally and applied, of course with the companion publications. Results that are also made public during large international conferences. The most important of the last years are :

- ⇒ “Conference on Fire Safety Design” in the 21st Century in Worcester, Massachusetts, USA in 1991.
- ⇒ “Engineering Fire Safety in the process of Building Design” in Belfast, Northern Ireland in September 1993.
- ⇒ “Fire Safety by Design” in Sunderland, England in July 1995.
- ⇒ “International Conference on Fire Research and Engineering” in Orlando, Florida, USA in September 1995.
- ⇒ “Fire Safety Conference on performance based concepts in Zürich, Switzerland in October 1996

SOLUTION : research & development

For certain assignments N.V. IFSET S.A. collaborates with the Fire Research Station from England, a well known research institution.

Until 2005 the FRS has a research program of 10 years going, including projects on middle long term (5 years) and long term (10 years).

An international co-ordination program with other researchers has been started up simultaneously to execute a continuous update of the results.

Following components are considered separately :

1. Fire initiation and development

Basic research to the start of a fire investigates the characteristics of the used materials and the speeds of extension as well as the physical powers produced by the smoke propagation and the combustion products.

2. Combustion products and smoke development

How will smoke and combustion products spread in corridors, shafts and channels ? What is the influence on the ambient temperature and can this be supported by the persons present ?

3. Passive fire protection

This is important in case of a fully developed fire.

How and how long can a building structure keep this fire within a determined space and what is the compartment of the structure on the developed temperatures ? Here the use of full scale tests, followed by computer simulations, replaces the traditional oven tests.

4. Detection

The 3 detection methods (heat, smoke or flames) are tested in 3 fields : speed of reaction, to avoid false alarms and correct installation. Tests are also done on basis of combustion gases and their typical chemical composition.

5. Active fire protection systems

Here the interaction of water on a fire is analysed. Here drop size and pressure are very important. The extension of a sprinklered fire and the smoke gas temperature are analysed. Smoke extract systems with improved technical execution are also developed, as well as the interaction between smoke extract and sprinklers.

6. Evacuation

The time to evacuate is the sum of the reaction time after the start of the fire plus the time necessary to reach a safe place. What signals are quickly recognised and how can the zone of danger be left quickly, of course based on the foreseen width of the escape roads but also on the adequate location of these, the indications, the maintenance and the repeated training. What is the importance of disabled people and what with a phased evacuation in places where a great lot of people is present ?

7. Characteristic Design Data

Hereby the drawing up of an enforced repartition of buildings, their destination and degree of occupancy is objectived at. The importance of ventilation openings (expressed in percentages) to the propagation of fire and the smoke density with regard to the used materials form another field of research.

8. Fire statistics and investigation

The analysis of known figures of earlier fires, the connection of similarities to these and the composition of a databank in which these data can be asked for in an interactive way.

9. Risk assessment

This is the ultimate objective for a fire safety engineer : propose an agreeable risk to integrity of furniture and persons based on the known design data (building, structure, layout, destination, occupancy) and the possibility to let this risk factor vary by a change in the fire safety design (probability bases simulation method). The F.R.A.M.E.-method can be considered as a trend-setter. This illustrates once again what was said in the introduction : THE solution does not exist, the best consensus has to be searched together with the project team and the authorities.

Thorough research still takes place in following organisations and institutes :

- The "National Fire Protection Association" (NFPA), the "National Institute of Standards and Technology" (NIST), the "American Society for Testing and Materials" (ASTM) and the "Society of Fire Protection Engineers" (SFPE), assisted by several universities, are actually working on an ambitious program in the USA to complete the existing prescriptive NFPA standards with a purpose aimed part. Therefore they do not speak of Fire Safety Engineering but of Performance based Design.
- The "International Standards Organisation" (ISO) has its own working group that has applied on Fire Safety Engineering, namely the Technical Committee 92, Subcommittee 4. They work in close collaboration with the "Centre International des Bâtiments" (CIB) and more specifically with the groups W14 and TG11.
- The "Fire Research Institute" in Japan, only little is available in English.
- Australia (University of Sydney) and Canada (National Research Council) are working together on an implementation model risk/costs

- Great Britain and New Zealand already dispose of research work translated in a standard : “The application of Fire Safety Engineering Principles to Fire Safety in Buildings” (UK), “Fire Engineering Design Guide” (NZ).
- The Lund university in Sweden, in collaboration with the Swedish National Testing and Research Institute, does a lot of research in the field of design fire sizes.

3. FIRE SAFETY ENGINEERING IN PRACTICE

With all the research work and the new regulation it is in all respects intended to come to practical design methods for fire safety. Therefore the objective of FSE must first be defined, a definition with eventual nuances and not internationally established. A good approach could be the following :

“Fire Safety Engineering” intends the application of design principles, regulation and an expert evaluation, based on a scientific concept of the fire phenomenon thus resulting in :

- * *the saving of lifes, the protection of goods and the protection of the environment and patrimony ;*
- * *the determination of risk and dangers of fire and the consequences*
- * *the analytic evaluation of the optimal protection and prevention measurements necessary to limit the consequences of a fire within certain determined limits.*

The way to follow during the elaboration phase is clearly more intrinsic than the application of some prescriptive rules. I hereafter give the most important differences in a nutshell.

Prescriptive rule

- Generally effective within a certain field of application
- Specification of the construction possibilities, limitation of dimensions and determination of the protection systems without reference to a certain protection purpose.
 - A fire safety objective is not put forward.

Performance design

- Establishing the objectives of a unique design.
- Defining calculation models that enable the realisation of these objectives.
- Indication of the instructions possible in this specific case.
- Different solutions are possible to obtain the same objective.

The preferment design passes different stades. It is a process by which all the preceding steps have to be completed in order to obtain a good result.

These steps are :

- Determination of the fire safety objectives.
- Assume objectives and criteria.
- Definition of fire scenarios that are applicable.
- Choice of the adequate calculation methods (models).
- Development of a solution.
- Put this solution into practice in the total design and eventual adaptation to external data.
- Obtain the approval for the proposed solution.

Let us have a closer look at these steps.

1. Objective of the fire security

General wordings determine what is expected of the measures taken. The desired final objective is specified, regardless of any other assumption. Therefore to avoid “flashover” is not an objective because it contains the assumption of “if this, than that”. The objective is given in

measurable quantities such as the maximum loss of human lives, the expected damage to building and furniture, the loss of market share after a fire, the impact on the environment by the quantity of noxious products.

Some examples :

- "Everyone in the building and not in touch with the fire can safely evacuate".
- "Limit the damage to X m² of the storage room".

2. Indicate other possible dangers

Persons present, furniture, type of the building, installation ... must be analysed and eventually possible bottlenecks must already be indicated.

Examples :

- % of the persons present are disabled persons.
- The building contains an atrium.
- Flammable products are used when working.

3. Formulate objectives and criteria

For the fire safety objectives it is determined how the fire, the building or the persons present should behave in order to reach the determined objective. Examples are the preservation of the structure, avoiding human loss in the fire compartment concerned, evacuate the persons present in X minutes.

The objectives are put a bit more specific than the general objective and they indicate that a certain number of actions has to be taken to reach these objectives.

The criteria are the (maximum) values determined for individual elements in the event of fire, such as temperature and radiation heat.

Some examples :

- A structural beam may be exposed to a temperature of 300°C for 20 minutes.
- The quantity of noxious smoke gases in a certain space must be limited to 15 % .
- The smoke layer has a maximum temperature of 500° C.
- The radiation level on the floor is less than 20 kW/m².

Mostly these figures are adapted with a safety factor so that a number of uncertainties and conservative reflexes can be coped with.

4. Define the relevant fire scenarios

Here the fire to be expected is defined to which the necessary solutions must be searched in order to attain the objective. The fire scenario describes the critical factors such as source of ignition, place of the persons present and type of the present construction and accessories. Different scenarios must be examined so that all objectives can be realised.

There are for instance :

- a scenario with high probability such as a hospital patient smoking in bed and falling asleep.
- an exceptional scenario with a fast fire extension. An example of this is an oil or gas leak in a technical room where the vertical shafts act as fire spreaders.
- a specific, individual scenario for which a separate, fixed solution is written : A space where explosives are handled.

5. Choice of the calculation model

In function of the scenario chosen a calculation will have to be made, starting from the basic parameters chosen and from determined prior conditions (= supposition of an effective situation at the moment of the fire). In view of the complex calculations and the quantity of parameters computer programs are used.

- FPETOOL is a fast calculation model for simple calculations.
- CFAST is a known American software model for fire propagation with a packages HAZARD I and FASTLITE.
- ASKHPM is developed in England and calculated smoke development in compartments and large spaces.
- Computational Fluid Dynamics uses a field model whereby the evolution of the fire is visualised.
- EXODUS visualises the flux of evacuating persons.

To use these models the designer must have a thorough knowledge of the possibilities and restrictions of the application, he must be able to judge the importance of an exact input and to make a good evaluation of the results. The fact is that these results make FSE possible and accepted in practice.

The result of the calculation model forms the basis for the security solution that is chosen.

6. From solution to execution

By using passive and active security methods, the solution is incorporated in the design (structural reinforcements, fire detection, sprinklers, selfclosing doors, ...).

The solution for a scenario is accurately written down and will also indicate how the objective is realised. The scenarios are treated one after the other and the package of solutions is submitted to the client and legislative and/or controlling instances.

The best is to make the evaluation and the control of the solutions in the presence of the designer so that it is possible to anticipate quickly on new project data or renewed objectives.

The proposed solutions come with a statement that the assumed objectives will be reached :

- implementation in the project is technically possible.
- control during the construction works if the basis parameters and the prior conditions are realistic.
- control if the execution of the design is done by qualified personnel.

“A good subsequent control confirms that the project is realised respecting the proposed solution following a design that reaches a determined security level and that the possibility of the building reaching this security level has been proved by qualified persons using the exact methods and the exact data.” This also is a good definition FSE.

4. DESIGNS WITH FSE + PRACTICAL EXAMPLE

If a complete design is wanted than the different stadia of fire extension, fire combat and evacuation must be gone through. As said in point 2, a research program in all these fields is active at the Fire Research Station. In the British manual (Code of Practice) "The application of Fire Safety Engineering Principles to Fire Safety in Buildings" this has been converted in 6 subsystems :

- SS1 Initiation and development of fire
- SS2 Spread of smoke
- SS3 Fire spread beyond compartment of origin
- SS4 Detection and activation
- SS5 Fire brigade communication and response
- SS6 Evacuation

Annexed there are 6 flowcharts presenting, at a single glance, how the complete process of FSE can be gone about. QDR means Qualitative Design Review and this means that an input can be given by the design team, considering the project possibilities of the moment. It is once again demonstrated that it is important to incorporate the fire security design from the start of the project. If the start of the project is within a month (or even worse if there is only 1 month before completion) all project parameters became so rigid that in most of the cases it is impossible to have cost-cutting adaptations.

Practical example

Last year N.V. IFSET S.A. made, together with the Fire Research Station, a design of SMOKE CONTROL (which was part of the FSE-CONCEPT) for "THE ESPLANADE - THEATRES ON THE BAY" in Singapore which was new to build. With a few plans and the technical report a real example of the extensive work required for such a complex structure is given. (AD HOC presentation).

5. STANDARDS AND PUBLICATIONS

During and after the presentation the participants can have a look at some basis works and application manuals. Hereafter an index :

- Conference proceedings of the mentioned congresses (se 2 : Research).
- BSI-draft standard : "Fire Safety Engineering in Buildings" (BSI - UK).
- Fire Engineering Guidelines (Fire Code Reform Centre Limited - Australia).
- Building and Fire (T. Shields & G. Silcock - UK).
- Design against fire (P. Stollard & L. Johnston - UK).
- Designing for fire safety (G. Butcher & A. Parnell - UK).
- Fire from first principles (P. Stollard & J. Abrahams - UK).
- SFPE Handbook of Fire Protection Engineering (SFPE - USA).
- Brandbeveiligingsconcepten (The Netherlands).
- Fire Safety Engineering (Tijdschrift - UK).
- Fire Engineers Journal (Tijdschrift - IFE).

6. CONCLUSIONS

Fire Safety Engineering promises to become more important in the future. The advantages of this objective aimed approach of the fire safety question are therefore clearly present :

- Complex buildings can apply to severe exigencies regarding fire damage losses without to many concessions to the architectural freedom. Today, airport buildings, stadiums, shopping centres, theatres, atrium hotels can, legally, not be built.
- The construction costs can be reduced without touching the security level.
- The legislative authorities can replace or improve surpassed traditional rules and formulate new texts with a certain coherence.
- A larger complementarity of passive and active safety measures is reached.
- Safety factors leading to higher insurance premiums can be reduced.
- The causal research of a real fire can be simplified.
- Drawing up and following a Fire Safety Management program becomes easier since the objective to reach (a fire save environment) becomes more tangible. Alterations to the building or the use of it can be evaluated and included in a more extensive concept.

Therefore it is necessary that, in the future, FSE is given a uniform approach. The existing prescriptive standards hereby form an obstacle since equivalent solutions are not known. Therefore a number of points must be determined on short term :

- What level of security must be assumed for the different types of buildings ?
- The research results in the different fields must be quickly put into usable texts and guidelines. Therefore, these must be put to legal texts and standards very quickly.
- New safety technologies must be channelled and the necessary education must be attended to.
- Engineers who are professionally occupied with FSE must receive a regular update.

As specialised engineering office we expect a co-ordinated collaboration of all parties involved in Belgium, the Ministry of Internal Affairs, the NVBB, the established fire security specialists, the universities and the fire brigade federations. In every way, a policy decision in that direction would be very welcome.

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