cost **TU**0904

Integrated Fire Engineering and Response

State of the Art Report

March 2011

COST- the acronym for European **CO**operation in the field of **S**cientific and **T**echnical Research- is the oldest and widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds.

The funds provided by COST - less than 1% of the total value of the projects - support the COST cooperation networks, COST Actions, through which, with only around € 20 million per year, more than 30.000 European scientists are involved in research having a total value which exceeds € 2 billion per year. This is the financial worth of the European added value which COST achieves.

A bottom up approach (the initiative of launching a COST Action comes from the European scientists themselves), à la carte participation (only countries interested in the Action participate), equality of access (participation is open also to the scientific communities of countries not belonging to the European Union) and flexible structure (easy implementation and light management of the research initiatives) are the main characteristics of COST.

As precursor of advanced multidisciplinary research COST has a very important role for the realisation of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a ridge towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of Networks of Excellence in many key scientific domains such as: Biomedicine and Molecular Biosciences; Food and Agriculture; Forests, their Products and Services; Materials, Physics and Nanosciences; Chemistry and Molecular Sciences and Technologies; Earth System Science and Environmental Management; Information and Communication Technologies; Transport and Urban Development; Individuals, Society, Culture and Health. It covers basic and more applied research and also addresses issues of pre-normative nature or of societal importance.

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PREFACE

"Integrated Fire Engineering and Response"

When the COST Action TU0904 was proposed, its "big idea" lay in including the word **Integrated** in its title.

Current practice in the European Union is that Fire safety is nationally managed, and the ways in which this happens are determined by the specific experiences of each country. A good example of this influence of history is the United Kingdom, for which a single event, the Great Fire of London in 1666, radically changed the way houses were constructed, with the avoidance of fire spread being the most important objective. Fire regulations in the UK (particularly in England) still reflect the determination of legislators to avoid similar events. While the political motivations for this approach are obvious, and local circumstances vary between countries, it can easily lead to similar processes having to be re-researched and re-invented country by country. In the context of the European Union and the introduction of common standards in areas related to fire

Figure 1: The Great Fire of London, 1666. A contemporary engraving

safety, it seems obvious that in such an important area the sharing of experience and research should be facilitated, and hence the need for networks in the COST model.

However, the need for integration has a further dimension. Fire engineering researchers tend to specialise in areas such as fire dynamics, structural fire engineering, active/passive fire protection, environmental protection or human response. Since the background sciences of these disciplines are different there is little interaction between them. Practitioners, including fire engineers, building/fire control authorities, and fire-fighters tend to consider fire safety as a whole, but lack in-depth awareness of recent advances in research and are outside the academic research networks. Through encouraging the exchange of information on different aspects of fire engineering and response between researchers in different countries, the network intends to create an awareness of the current state of the art, and to avoid repetition of research. The non-research community will benefit from exposure to advanced research findings, discussion with researchers, and the sharing of best practice. Their input will make researchers aware of real-world constraints, and where new research and standards are needed.

The Action divides its membership _loosely_ into three themed Working Groups, although clearly its overall mission of promoting integration means that these groups must interact on many of the key activities. The Working Groups are:

WG1. Fire Behaviour and Life Safety focuses on the behaviour and effects of fire in buildings, combining this research-based knowledge with the most effective means of protecting human life against the occurrence of fire in the built environment. This includes active measures in fire-fighting with the effects of building form on the inherent risk to inhabitants.

WG2. Structural safety covers the response of different building types to fires and the rapidly developing research field of structural fire engineering, including new materials and technologies and passive protection measures. Crucial problems of structural fire engineering concern change of use of buildings and the current imperatives of sustainability, energy saving and protection of the environment after fire.

WG3. Integrated Design brings together design, practice and research across the disciplines of fire in the built environment. In structural design this includes integration of fire resistance with all the other functional requirements of a building, from concept onwards, rather than simply adding fire protection

after all other processes are complete. Active input from practitioners, regulators and fire-fighters through this group is vital to the success of the Action.

The Action started in July 2010, and now has 22 nations of the EU as participants. Its first "deliverable", which attempts to bring together the current state of research, mainly in the participating countries but set into the context of knowledge world-wide, is this State of the Art Report. For this document the material is grouped according to its relationship to the three Working Groups, and has been collated by their chairmen from theiur membership. In the case of WG1 and WG2, which are active academic research fields, the articles comprise brief résumés of key research topics, together with the current state of progress, and themes, of the research centres of the participating nations. For WG3 the baseline is rather different, being based on current practice and the regulatory régimes within which fire engineering is carried out.   Hence an attempt has been made, via a detailed questionnaire sent to individual country representatives, to bring together relevant information on these issues. It is clear that further contextual issues will become apparent within the next 3 years of the Action, and both the questionnaire and its responses can be updated as the network reveals these issues.

Ian Burgess
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1 April 2011

WG1

Fire Safety

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FIRE BEHAVIOUR AND FIRE SAFETY

Overview

Performance-based fire engineering design is being adopted around the world as a rational means of providing efficient and effective fire safety in buildings.

Much activity is taking place today regarding fire-safe building design. The general trust is directed toward quantification procedures and identification of a rational design methodology to parallel or supplement the traditional "go or no go" specifications approach. Knowledge in the field of fire protection is undergoing development and reorganization that will enable buildings to be designed for fire safety more rationally and efficiently.

The acceptable levels of safety and the focus of the fire safety analysis and design process objectives are concentrates in the following five areas:

1. Life Safety

2. Property Protection

3. Continuity of operations

4. Environmental protection

5. Heritage conservation

Factors influencing the performance required from a specific fire engineering design include:

- building geometry and intended use;

- location of properties;

- probability of a fire occurring;

- fuel load and distribution;

- number and abilities of occupants;

- available water supply and

- fire protection systems: smoke control installation, sprinkler system,…

Fire scenarios

A fire scenario is generalized, detailed description of an actual or hypothetical, but credible, fire incident. Each fire scenario includes all details relevant to the development of a fire and subsequent behaviour of people and mechanisms of protection. They may include events such as: ignition, fire spread, extinguishment, smoke production, flashover, smouldering or flaming combustion and evacuation. And conditions are represented by: materials, environment, detection systems, life support systems, energy sources, and suppression systems.
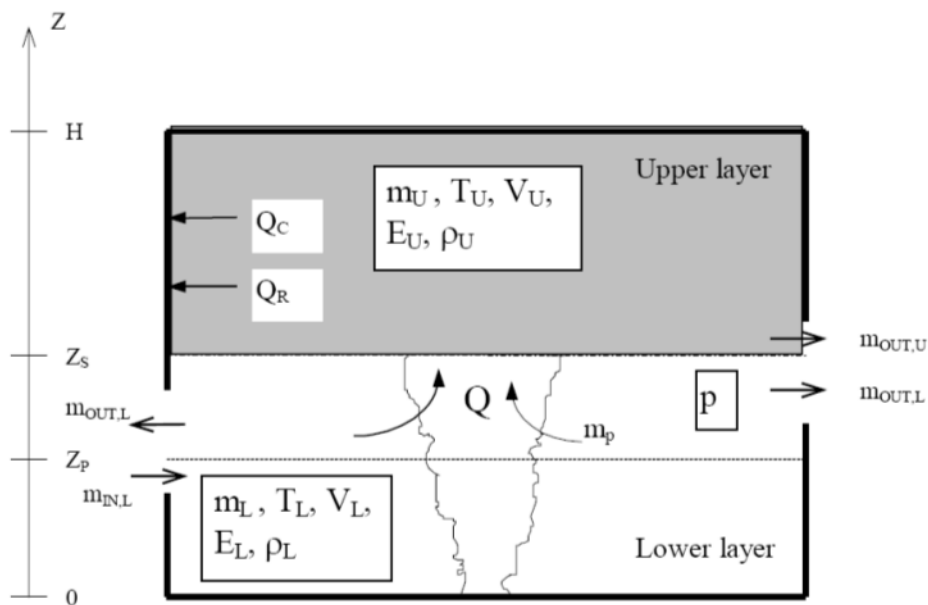
Development of fire scenarios requires a constructive use of imagination. Judgment and extrapolation are very important because only limited data are available.

References:

"Valorisation project-Natural fire safety concept" – European Commission

RFCS project: "Natural fire safety concept" – European Commission

Design Fires

Many assumptions are made in the modelling process. One of the most important is the design fire, which is required as input for nearly all fire growth computer programs.

Most fire growth models require the user to input a design fire as a specified heat release rate varying with time. The design fire is the heat release rate for the fuel assuming that it is free burning in the open air.

Liquid fuels burning in the open, as pool fires, tend to burn at a constant rate once steady state conditions have been reached.

Any item of fuel may be assumed to have an increasing heat output according to a simple quadratic dependence on time. This is referred to as t2 fire. Scaling by a growth constant can account for a wide range of fire growth rates, from very slow to very fast. The particular choice of growth constant depends on the type and arrangement of the fuel.

The fire can be considered to grow according to the t2 curve until either the fuel is consumed, or until the heat release rate reaches a peak value expected for that particular object, in which case the duration of constant burning at that rate can be calculated.

References:

"Fire engineering design guide" – CAE University of Canterbury.

"Valorisation project-Natural fire safety concept" – European Commission

Fire evolution, propagation, suppression (active measures)

The fire load defines the available energy but the gas temperature in a fire depends on the rate of heat released. The same fire load burning very quickly or smouldering can lead to completely different gas temperature curves.

The RHR is the source of the gas temperature rise, and the driving force behind the spreading of gas and smoke. A typical fire starts small and goes through a growth phase. Two things can then happen depending if during the growth process there is always enough oxygen to sustain combustion. Either, when the fire size reaches the maximum value without limitation of oxygen, the RHR is limited by the available fire load (fuel controlled fire). Or if the size of openings in the compartment enclosure is too small to allow enough air to enter the compartment, the available oxygen limits the RHR and the fire is said to be ventilation controlled. Both ventilation and fuel controlled fires can go through flashover.
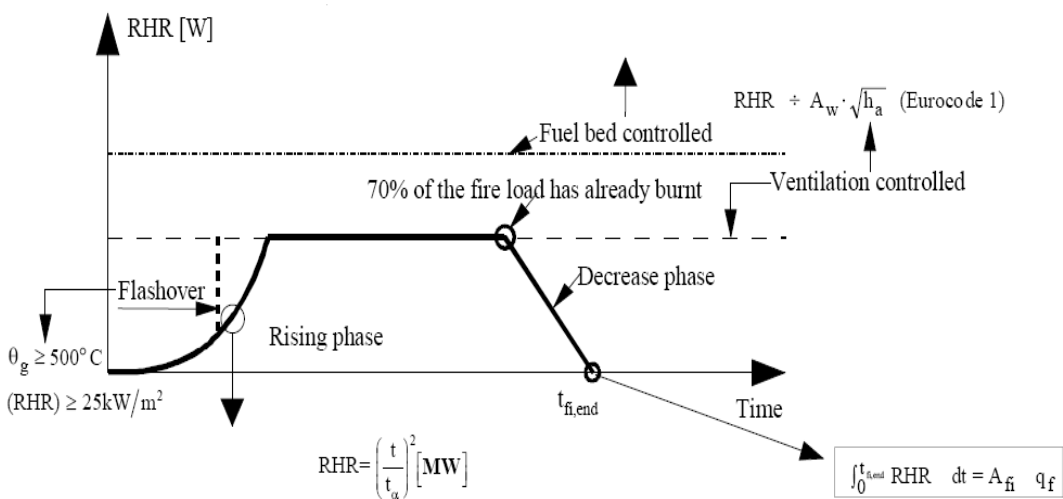
This important phenomenon, flashover, marks the transition from a localised fire to a fire involving all the exposed combustible surfaces in the compartment.

After the growing phase, the RHR curve follows a horizontal plateau with a maximum value of RHR corresponding to fuel bed or ventilation controlled conditions.

Finally, the decay phase is assumed to show a linear decrease of the RHR. Based on test results, the decay phase can be estimated to start when approximately 70% of the total fire load has been consumed.

On the other hand, in case of installation of fire suppression system, the decay phase can be considered to start when the first sprinkler starts to pour water and the reduction of RHR can be considered as exponential.

References:

"Valorisation project-Natural fire safety concept" – European Commission
NFPA 13: Standard for installing sprinkler system".

Compartment energy balance

The heat release has long been recognised as the major reaction to fire parameter because it defines fire size and this defines many other reactions to fire quantities e.g. smoke and toxic gas production.
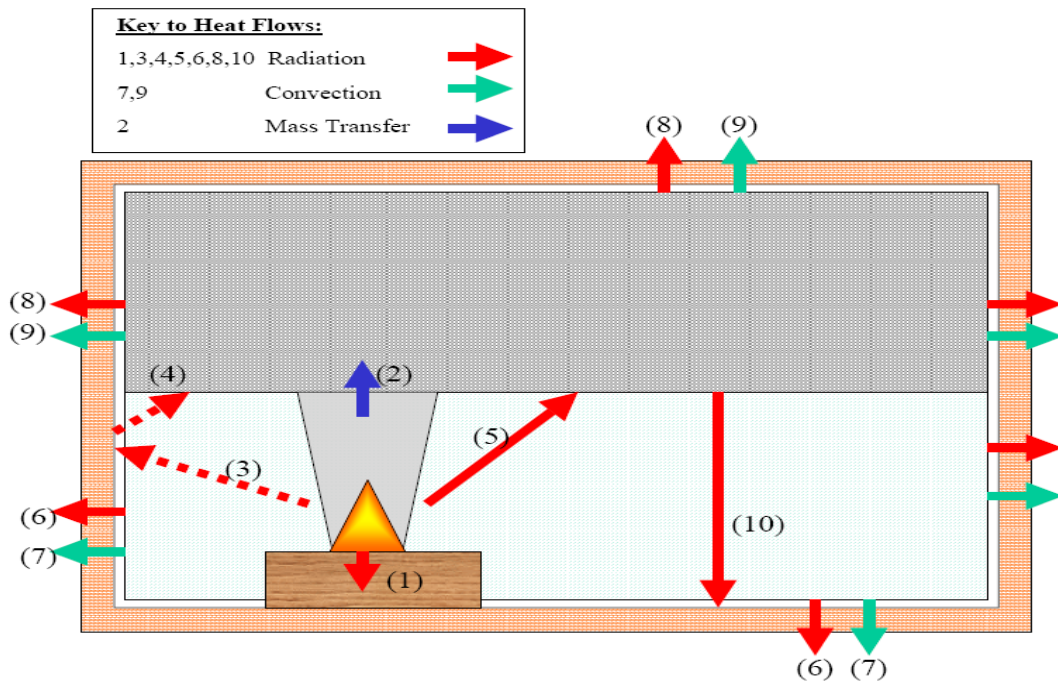
The rate and amount of heat transferred influence the rate of spread and the intensity of a fire. Combustion can not be sustained unless heat continues to be transferred. Heat transfer occurs by three means: convection, because of air and smoke motion; radiation as emission or absorption of electromagnetic waves; and conduction.

References:

"Fire engineering design guide" – CAE University of Canterbury.

"Risk-based fire resistance requirements" – ECSC Steel RTD programme.

Smoke control

Worldwide, codes on fire safety systems in buildings recognise the danger to life from smoke and require that buildings be designed and operated to prevent migration of smoke through the building.
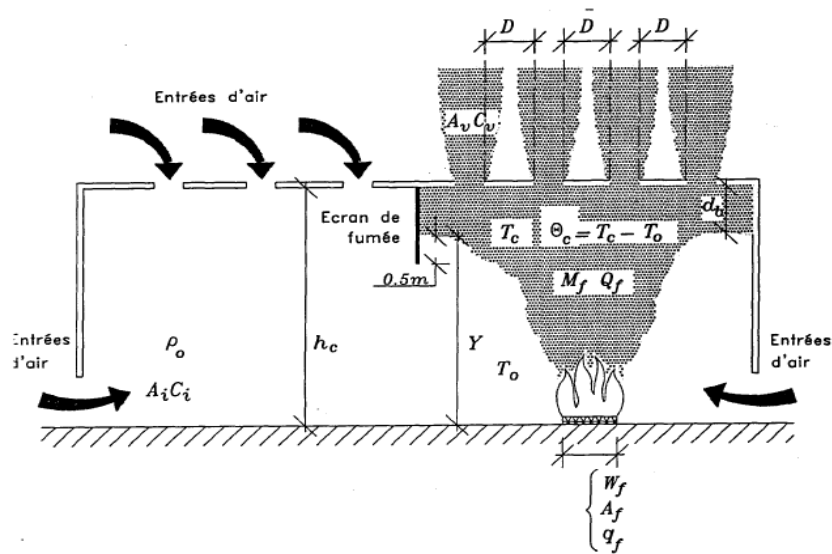
Occupant safety can be greatly improved by providing efficient smoke control and extraction systems. Moreover, such systems can limit property damage by limiting the spread of smoke and by providing better visibility and thus easier access to the seat of the fire for fire fighters.

There are three basic different purposes of a smoke control system:

- Life safety: the system is to be designed to maintain tenable conditions on escape routes.

- Fire fighting access/property protection: the system is designed to increase visibility, and reduce heat exposure.

- Smoke purging: the system is to be designed to enable smoke to be cleared from a building after the fire has been brought under control.

It is necessary to decide which of these, or combination of the three objectives is to be achieved before starting a design of smoke control system.

References:

NFPA 204: "guide for smoke and heat venting".

NFPA 92B: "Guide for smoke management systems in malls, atria and large areas".

NBN S-21-208-1:"Protection incendie dans les bâtiments-conception et calcul des installations dé evacuation de fumées et de chaleur.

Tenability conditions

Where zone-based fire growth models are used to predict smoke filing in compartments, the following tenability limits are recommended to identify when life threatening conditions may occur.

Convective heat – the temperature of the relevant gas layer should not exceed 65ºC (time to incapacitation for 30 minutes exposure (Pulser 1988))

Smoke obscuration – the visibility in the relevant layer should not fall to less than 2 m (optical density not greater than 0.5 m-1) (Tewarson 1988)

Toxicity – the following species concentrations lead to incapacitation in approximately 30 minutes (Purser 1988)

- CO: not >1400 ppm (small children incapacitated in half the time)

- HCN: not>80ppm

- O2:   not<12%

- CO2:   not >5%

The above limits for convective heat, smoke obscuration and toxicity apply to the lower layer if the height of the smoke layer interface above floor level is greater than 1.5 m (the approximate nose height of a standing adult), otherwise the limits apply to the upper layer.

Radiative heat – the radiant flux from the upper layer should not exceed 2.5 KW/m2 at head height (this corresponds to an upper gas layer temperature of approximately 200ºC). Above this, the tolerance time is less than 20 seconds (Purser 1988).

References:

"Fire Protection Handbook" 19th edition - NFPA International.

People evacuation

For all spaces in a building, the time taken to evacuate the space must be less than the time for the environment in that space to become life threatening, with a safety factor, so that:

$$t_{ev}.SF < t_{lt}$$

where t_{ev} is the calculated evacuation time measured from the ignition

   t_{lt} is the time for conditions to become life threatening, again measured from ignition

   SF is a safety factor.

The safety factor is required to provide a safety margin between the calculated evacuation time and the time by which occupants must have escaped.

A safety factor of 2 is suggested for able-bodied people to allow for uncertainties in calculating the likely times, difficulties in finding the way and other unforeseen circumstances.

However, today there is computer tools which use lots of information, to calculate more accurate evacuation time, that is why the safety factor can be reduced.

References:

"Occupant behaviour and evacuation" – National Research council Canada.

"Engineering guide to human behaviour in fire" – SFPE.

"Fire Protection Handbook" 19th edition - NFPA International.

Rescue and intervention

Fire departments use personnel with specialized skills who are organized into various operational and staff units who are fully qualified and capable of efficiently performing the wide range of services necessary to protect life and property.

Whatever the circumstances surrounding an incident, perhaps the most important consideration is the preservation and safety of the rescue personnel. An appropriate motto for rescue personnel should be "do not become a victim". Response organizations should establish a systems safety approach to all rescue operations in order to limit the risk to rescuers, while maintaining a viable and effective response and operational capability

References:

"Fire Protection Handbook" 19th edition - NFPA International.

Jose Torero

OBJECTIVES OF FIRE SAFETY

Because fire represents a threat to life, property and the environment, there is a need to control its impact in such a way that life is fully protected, and damage to property and the environment are minimized. Fire Safety is the means by which infrastructure is designed in a manner such that these goals are achieved [1].

The schematic presented in Figure 1 represents the possible sequence of events during a fire in a building. The safety objectives for a building can be quantified in terms of the different characteristic times of the events. It follows that the time needed to evacuate a particular compartment, $t_{e,i}$ is required to be much smaller than the time to reach untenable conditions in that compartment, $t_{f,i}$. The characteristic values of $t_{e,i}$ and $t_{f,i}$ can be established for different levels of containment, i.e. room of origin (i=1), floor (i=2) and building (i=n). Furthermore, it is necessary for the time to evacuate the building to be much smaller than the time when structural integrity starts to be compromised (t_S).
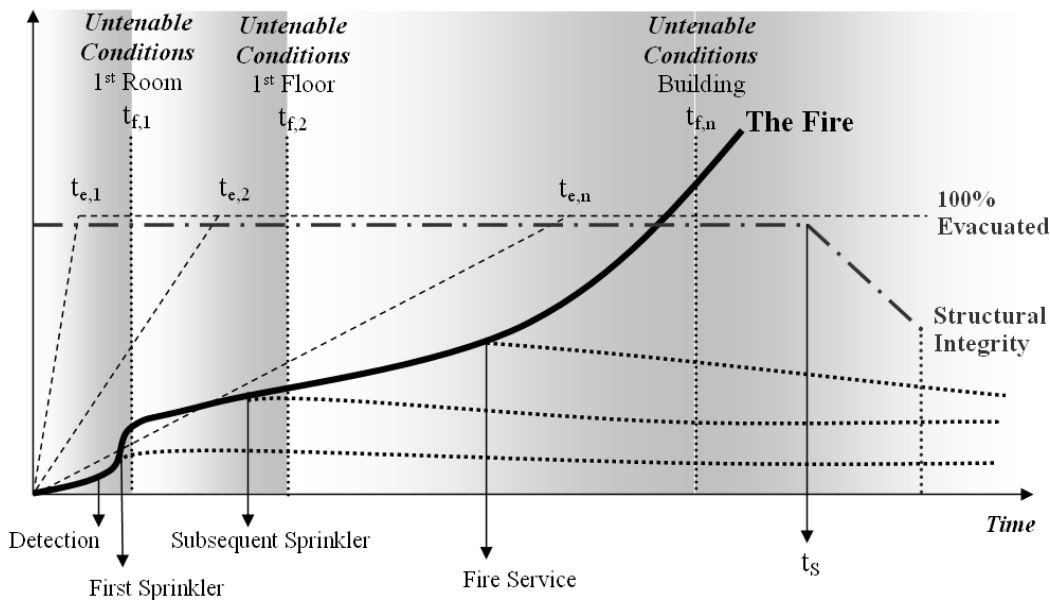
Figure 1: Schematic of the sequence of events following the onset of a fire in a multi-storey building [1]. The solid line corresponds to the "fire size", the dotted lines to the possible outcome of the different forms of intervention (sprinkler activation, fire service). The units of "fire size" could be defined as heat-release rate, area of fire or any other means to quantify the magnitude of the event. The dashed lines are the percentage of people evacuated for the room, floor and building respectively, with the ultimate goal of 100% represented by a horizontal dashed line. The dashed & dotted line corresponds to the percentage of the full structural integrity of the building.

In summary:

$$\forall i, \ i=1 \text{ to } n; \ t_{e,i} << t_{f,i} \tag{1}$$

$$\forall i, \ i=1 \text{ to } n; \ t_{e,i} << t_S$$

It could be added to these objectives that full structural collapse is an undesirable event however long the fire lasts, therefore:

$$t_S \rightarrow \infty \tag{2}$$

Although these generalized criteria for safety times are a simplified statement, they describe well the main objectives of a fire safety strategy (Torero 2009).

When designing for fire safety, a number of strategies are put in place aiming at achieving these objectives. These include those factors which are intended to increase t_S and $t_{f,i}$, such as active (e.g. sprinklers, or the intervention of the fire service) and passive systems (eg. fire proofing or compartmentation). As shown by Figure 1 (the dotted lines branching off below the Fire curve) success of these strategies can result in control or suppression of the fire. Passive protection such as thermal insulation of structural elements becomes part of the design, with the purpose of increasing t_S. Finally, but most importantly, evacuation protocols and routes are designed to reduce $t_{e,i}$ at all stages of the building evacuation. It is important to note that the safe operation of the fire service within these times needs also to be included in the design.

Figure 1 makes clear that Fire Safety is the superposition of three different types of events occurring simultaneously. Two of these events, egress and structural behaviour, are reactive events while the rate of fire growth is the driving process. The structure will be designed and it will respond to the fire. Some passive fire protection systems (detection, alarm) are designed and implemented to warn of the fire, and others are designed to affect the rate of growth (suppression). People within a building are located according to the general use of he premises but will change their behaviour in response to the fire. Occupants will have mostly a passive role, while fire fighters will have an active role attempting to control the growth of the fire.

Building design and fire fighter intervention procedures are defined on the basis of one or more fire growth scenarios. In the case of prescriptive design (codes and standards) the fire growth scenarios are implicit, while in the case of performance-based design (engineering based methods) they are explicitly defined and are referred to as "design fires". Prescriptive design rules use knowledge on fire dynamics and empirical data to bound the fire growth for the specific conditions of the implied scenarios. Fire safety systems are designed to operate within these bounds and are deemed adequate for a range of building. But given that there are unavoidable and significant differences between buildings, there is a risk of extrapolating codes and standards outside its range of applicability. Therefore, to know the extend of the extrapolation of prescriptive solutions requires understanding the parameters that govern and bound the fire growth scenario. In the case of performance-based design, knowledge on fire dynamics is used to predict fire growth under the particular conditions of the building. Thus the link between fire safety objective and understanding of the physical parameters controlling fire growth is important and explicit.

Basic Definition of Fire Growth

While Figure 1 implies that there is a single variable to quantify fire growth, the reality is that there are many different variables. The variable or variables of interest depend on the objective of the system under design.

At the core of a fire there is a flame or a reaction front that is effectively a combustion process, and thus is governed by the mechanisms and variables controlling combustion. The interaction between the fire and the environment determines the behaviour of the flame and nature of the combustion processes. This is commonly referred to as Fire Dynamics. An extensive introduction to the topic is provided by Drysdale (1998).

As indicated by Drysdale, Fire Dynamics involves a compendium of different sub-processes that start with the initiation of a fire and end with its extinction. The onset of the combustion process, i.e. ignition, in a fire is a complex process that implies not only the initiation of an exothermic reaction but also a degradation process that provides the fuel feeding the fire. In a fire it is common to have different materials involved and given the nature of the fire growth many could be involved simultaneously but others sequentially. The sequence of ignitions of items in an enclosure will affect the nature of the combustion processes. Thus,

ignition mechanisms set the dynamics of the fire and also are affected by the fire itself, creating a feedback loop.

Once a material is ignited, the flame propagates over the condensed fuels by transferring sufficient heat to the fuel until a subsequent ignition occurs. This process is commonly referred to as flame spread and is described in detail by Fernandez-Pello and covered in section 5 of this chapter. Flame spread defines the surface area of flammable material that is delivering gaseous fuel to the combustion process. The quantity of fuel produced per unit area is the mass burning rate. The mass burning rate multiplied by the surface area determines the total amount of fuel produced. If the total amount of fuel produced is multiplied by the effective heat of combustion (energy produced by combustion per unit mass of fuel burnt), it yields the heat release rate. The heat release rate is generally considered the single most important variable to describe fire growth (Babrauskas 1992). Given the nature of the environment, the oxygen supply might not be enough to consume all the fuel, thus in many cases combustion is incomplete and therefore the heat of combustion is not a material property but a function of the interactions between the environment and the fire. In these cases it is usually deemed appropriate to calculate the heat release rate as the energy produced per unit mass of oxygen consumed multiplied by the available oxygen supply.

A fire can end when it is extinguished or when oxygen or fuel supplies are depleted (oxygen starvation and burnout respectably). In all cases, extinction of the combustion process is brought by interactions of fuel and oxygen supply and the energy balance that permits the combustion reaction to remain self-sustained. Suppression agents affect a fire by reducing fuel and oxygen supply or by removing heat (ie. disturbing the fire triangle). At each stages of fire growth, it is more or less feasible to affect these three variables. Thus the effectiveness of a suppression system is dictated by its capability to affect the targeted variables at the moment of deployment.

The overview by Torero describes all the above processes in more detail extracting at each stage the main material properties and physical parameters that affect fire growth and how they relate to the fire safety.

References:

JL Torero and G Rein, Physical Parameters Affecting Fire Growth, Chapter 3 in: Fire Retardancy of Polymeric Materials, 2nd Ed, Editors CA Wilkie and AB Morgan, CRC Press, Taylor & Francis, 2009. ISBN 978-1-4200-8399-6.

Williams, F.A., Combustion Theory, Second Edition, The Benjamin/Cummings Publishing Company, Inc., 1985.

Drysdale, D. "An Introduction to Fire Dynamics," John Wiley and Sons, 2nd Edition, 1998.

G. Cox (Editor), "Combustion Fundamentals of Fire," Academic press, 1995.

Babrauskas, V. and Grayson, S.J. (Editors), "Heat Release in Fires,", Elsevier Applied Science, 1992.

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REVIEW OF DESIGN FIRES IN BUILDINGS

The definition of fires of assumed characteristics, design fires, is one of the most important steps when considering the fire safety of buildings. Design events are those fires that are expected to occur over the life of the building for which the building is expected to meet its design safety objectives. Design fires are determined as fires that are reasonably expected and which represent the maximum threats that should be mitigated. Fire characterisations have been based on the survey (inventory or web-based questionnaire) of existing buildings, fire tests, mathematical fire modelling or combinations of all these. Normal, lognormal, 3-parameter gamma and Gumbel distributions have been used for the statistics of the data and mean and fractile values from 80 % to 95 % are used to give the design fires. In the most novel European standards the fire load densities (MJ/m^2) are given as 80 % fractile values supposing Gumbel distribution. Maximum rates of heat releases are given for different occupancies in the standard, too. In the literature for some cases 95 % fractiles are recommended to be used. In special cases very severe design fires are proposed. In some cases fixed (building's structures) and movable (building's combustible contents) fire loads are given separately, in some cases not.

Fire load survey of commercial premises in Finland

Thirty commercial premises were surveyed using the inventory method in the city of Seinäjoki, Finland, during spring 2010. The total floor area was about 28000 m^2, the smallest shop was 54 m^2 and the largest 4550 m^2 + store 800 m^2. Fixed fire loads (MJ/m^2) were studied separately for floors and for walls/ceilings as well movable fire loads were considered. The movable fire loads were distributed in wood, paper, textiles, plastics and others following similar distributions in the literature. The fire loads varied between 115-1787 MJ/m^2. The largest value (1787 MJ/m^2) did not include any fixed fire load, only movable loads. The sample was fitted to lognormal and Gumbel distributions. The χ^2 test showed that the lognormal distribution describes the sample little bit better than Gumbel. The 80 % fractile value was 635 MJ/m^2 using the lognormal distribution and 623 MJ/m^2 using Gumbel. Based on this study and recent French study for similar samples the Eurocode value is proposed to be proper to be used in commercial premises. The fire loads for storages should be calculated based on the stored materials.

References:

Björkman J., Autio V., Grönberg P., Heinisuo M., A paper will be proposed to Prague Fire Conference, April, 2011.

Design fires for fire safety engineering

The report describes an approach to fire characterisation that is based on the concept of fire load entities. Entity means a fundamental 'unit' that is describing the initial fire, not only MJ/m2 but also heat release versus time. The initial fires are quantified using heat release rates which are dependent on the usage of the building. Assessment of fire growth and spread is based on the capability of the FDS to make conservative estimations how rapidly and how large a fire may grow within a given space. The report summarises the basics of performance criteria, fire safety engineering process and procedure for estimation of initial fires and fire development. Design fires for different occupancies are described in detail: sports and multipurpose halls, dwellings, warehouses and shops. Key issues concerning timber structures under design fire exposures are described. Comprehensive list of references is included.

References:

Hietaniemi J., Mikkola E., Design Fires for Fire Safety Engineering, VTT Working Papers 139, VTT, 2010, 101
    pages. ISBN 978-951-38-7479-7 (URL:http://www.vtt.fi/publications/index.jsp), ISSN 1459-7683
    (URL:http://www.vtt.fi/publications/index.jsp)

Fire load distributions in the program to prevent fatal events in fire

Preliminary survey of fire loads in residential houses in Finland was done during 2003-2005. Totally 67 houses were surveyed by the students of the Fire Safety College of Finland. Data was collected for three types of buildings (single family houses, bungalow typed houses, block of flats) and for the different use of the rooms. Data was collected for movable and fixed fire loads (MJ/m^2), and the fixed loads are given separately for floors, walls and ceilings. Lognormal distribution was used when evaluating the data. A combination of fixed and movable fire load lognormal distributions is proposed. No proposal is given for the design values. This preliminary study is planned to be continued in the near future.

References:

Keski-Rahkonen O., Karhula T., Hostikka S., Palokuormien jakaumat palokuoleman ehkäisykeinojen
    arviointiohjelmassa, Palotutkimuksen Päivät, 2009, pp. 108-114 (in Finnish).

Fire load survey and statistical analysis

Statistical results based on a survey in 475 rooms including hotel, hospital, shopping centers, offices and industrial buildings are presented. 336 rooms were in Switzerland and in Lichtenstein and 139 rooms in France. Fixed and movable fire loads were observed. Sets of parameters (e.g. based on use of the building) were found using last squares method and a chi-square test. The lognormal was found to give always satisfactory results while Gumbel law can be used if the coefficient of the variation is less than 1.0. Wood was found to be in shopping areas, hotels, offices and hospitals very often the main material for the composition of the fire load. In Swiss production areas 95 % of the fire load densities are lower than 2500 MJ/m2. The mean value is 1080 MJ/m2 and the standard deviation 1920 MJ/m2. For storage areas the same numbers are: 35000 MJ/m2, 11874 MJ/m2 and 32774 MJ/m2. The sample includes one silo with 433710 MJ/m2. Without this the mean is 9806 MJ/m2 and the standard deviation 14055 MJ/m2, twice smaller than before. In French study 26 stores were surveyed, 90 % of fire load densities are in the range 0 – 910 MJ/m2 with the mean and the standard deviation 571 MJ/m2 and 372 MJ/m2. The results are compared to the Eurocode values.

References:

Thauvoye C., Zhao B., Klein J., Fontana M., Fire Loa Survey and Statistical Analysis, Fire Safety Science –
    Proceedings of the Ninth International Symposium, 2008, pp. 991-1002.

Fire load survey of historic buildings: A case study

The results of a fire load density survey carried out in Ouro Preto, Brazil, are presented. The survey covered 43 historic baroque buildings, some of which were built in the latter part of the 17th century. The buildings were divided in a variety of occupancies, with residences and commercial stores being most frequent. The inventory method was used with all buildings, which were researched for their fixed and movable combustible contents. The average fire load density was 2989 MJ/m2 with the standard deviation 2833 MJ/m2. In a drugstore a single maximum density of 14,560 MJ/m2 was found. Wood contributes a substantial portion of fire load, being 35 % of movable load and 37 % of fixed fire load. The measured values could exceed Brazilian standard NBR 14432 values by up to a factor of 10. In the paper is listed four main reasons why these kinds of buildings are particularly vulnerable to fires.

References:

Claret A., Andrade A., Fire Load Survey of Historic Buildings: A Case Study, Journal of Fire Protection
Engineering, Vol. 17-May 2007, pp- 103-112.
(http://jfe.sagepub.com/gci/content/abstract/17/2/103)

Determining design fires for design-level and extreme events

Difference between design level and extreme events is clearly stated in the paper. As an example design winds for buildings do not cover hurricane winds. Tornados are considered extreme events against which buildings are not expected to perform. History of fire load surveys starting at Ingberg 1928 is briefly referred. Fire load (MJ/m2) representations using 90 % or 95 % fractile values are recommended. Problems to define the design fire loads are outlined based on: spread of fire, ventilation of the building, the existence of active and passive fire protection features and finally: fire is a stochastic event that is highly dependent on the conditional probabilities on mitigating factors, planned or unplanned. Finally: *It is possible to conduct extreme events analysis in a way that meets the growing need for risk informed regulation*.

References:

Burkowski R., Determining Design Fires for Design-level and Extreme Events, SFPE 6th International
Conference on Performance-Based Codes and Fire Safety Methods, June 14-16, 2006, Tokyo, 11
pages.

Medium-scale fire experiments of commercial premises

The report presents and discusses the results of a fire load survey and a set of medium-scale fire experiments to determine the burning characteristics of combustibles in commercial premises. The inventory method was used in 2003 in the Canadian cities of Ottawa and Gatineau for 168 commercial premises. The results simulate the fuel loads found in the different shops. Fuel packages consisting of high plastic, rubber and edible-oil content attained high peak heat release rates (1,300 to 1,950 kW) an exhibited fast fire growth and significant smoke production (0.96 to 2.74 OD/m). The paper also presents the test of the fuel packages simulating a fast food shop. The results show that the fire reached a peak heat release rate of about 1562 kW at 6.5 minutes from ingnition, and a peak gas temperature of 735 ^{o}C in the hot layer. The fire load densities of all 168 stores surveyed have lognormal distribution with a mean of 747 MJ/m2 and a standard deviation 833 MJ/m2, indicating significant spread, as can be expected. 95 % fractile value is 2,050 MJ/m2 for all cases. For shoe stores (3 samples) and for general stores (43 samples) 95 % fractile values 4,612 and 4,289 MJ/m2 are given, respectively. The measured total HR values for clothing storage and fast food tests show excellent agreement with the results of the survey.

References:

Zalok E., Bwalya A., Hadjisopocleous G., Medium-scale fire experiments of commercial premises, NRCC-
45397, A version of this document is published in: 2005 Fire and Material Conference, San Francisco,
Jan. 31-Feb.2, 2005, pp. 1-12. (http://irc.nrc-cnrc.gc.ca/ircpubs)

A pilot survey of fire loads in Canadian homes

The report presents the results of a pilot survey of movable loads in residential living rooms located on the main floor and basement levels. The survey was conducted using a web-based questionnaire. The survey attracted 74 respondents. The efficacy of the survey methodology is discussed, and the main combustible furniture is identified. The main floor furniture was found to be similar but basements contained a greater variety of furniture. The values of fire load densities calculated using estimated weights of furniture were

within the range of values found in the literature. The results are given as mean values (in 74 homes) for main floor and basement living rooms (500-600 MJ/m2) and they are compared to US (200 and 70 rooms) and Japanese (214 rooms) survey results and to building code values in New Zealand (400-1200 MJ/m2) and Sweden (600 MJ/m2).

References:

Bwalya A., Sultan M., Benichou N., A Pilot Survey of Fire Loads in Canadian Homes, IRC-RR-159, NRC, March 9, 2004, 24 pages.

Literature review on design fires

The main parameters affecting fire development in small rooms are identified, together with the methods for characterizing design fires for pre-flashover and post-flashover stages. Numerous combustion data, from the fire tests involving real and mock-up furniture, from various laboratories around the world, was found. Large variations in furniture designs and materials as well in fire loads published during last two decades were found. The most important observation was an absence of fire load data for residential and commercial occupancies in Canada.

References:

Bwalya A., Benichou N., Sultan M., Literature Review on Design Fires, IRC-RR-137, NRC Publications Archive (NRArC), June 25, 2003, 31 pages. (http://nparc.cisti-icist.nrc-cnrc.gc.ca/npsi/ctrl?lang=en)

Fire loads in office buildings

Fire load survey of 100 offices is given. More than 1500 office rooms are considered. The distribution of fire load density found as a main result of the study. The mean of fire load per floor area seemed to be approximatively the same as in some other studies, 1000 MJ/m^2. The maximum rates of heat releases in different types of rooms were calculated as well as the worst realistic fire situations in some open plan offices and atria. Extreme value distribution was the best estimation to the distributions of fire load density, maximum rate of heat release, the amount of paper and the amount of machinery in fire load. This work has given a representative view of fire loads in Finnish offices, and allows a reliable foundation to performance-based fire safety design.

References:

Korpela K., Fire loads in office buildings, Master's Thesis, Department of Civil and Environmental Engineering, Helsinki University of Technology, Espoo, 1999, 84 + 115 pages (in Finnish).

Fire load in residential buildings

The results of a fire load survey carried out in Kanpur, India are presented. Thirty-five residential buildings with a total floor area of 4256.6 m2 were surveyed. The inventory method was used. The results show that the maximum and mean fire loads decrease with increase in floor area up to 16 m2, but thereafter it shows no variation with further increase in floor area. The results show no relationship between load magnitude and building height (up to three floors). The mean loads varied from 278 MJ/m2 to 852 MJ/m2 with an overall average of 487 MJ/m2. The standard deviation of fire load ranged from 87 MJ/m2 to 621 MJ/m2 with an average of 255 MJ/m2. A single maximum fire load of 2174 MJ/m2 was encountered in a storeroom. The storeroom and kitchen were found to be most heavily loaded. The fire loads contributed by the fixed load and the movable load are 52.66 and 47.34 %, respectively. The reduction in use of timber in structural and non-structural members may reduce the fire loading considerably, is given as a summary.

References:

Kumar S., Rao C., Fire Loads in Residential Buildings, Building and Environment, Vol 30, No 2, 1995, pp. 299-305.

Fire loads in apartments of block of flats

Survey of fire loads in 62 apartments in Finnish block of flats built during 1966 is reported. No differencies in fire loads were found between apartment types. The movable fire load parts were in entire apartments 60 %, in living rooms 85 %, in bed rooms 64 % and in kitchens 13 %. The data of this research has been recalculated (VTT, Tutkimusselostus NRO RTE1461/05) and Gumbel distribution is used for the data. After raising the results about 30 % the result was that the mean of the fire load for the entire apartment is 509 MJ/m^2 and 80 % fractile 575 MJ/m^2. The values for the movable fire loads are 321 and 390 MJ/m^2, respectively. The results are compared to the values of Eurocode for the entire apartment (780, 948 MJ/m2) and to US studies (Cambell J., Confinement of Fire in Buildings. Fire Protection Handbook. NFPA Handbook, USA, 1981, 320, 425 MJ/m^2) and to a Canadian study for living rooms (Bwalya A., An extended survey of combustible contents in danadian residential living rooms. Ottawa, Canada: National research Council Canada. Research Report No. 176, 2004, 445, 565 MJ/m^2).

References:

Holm C., Oksanen P., Palokuorman määrä kerrostalojen asuinhuoneistoissa. Palontorjuntatekniikka. Nro 2, 1970. pp. 1-4 (in Finnish).

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DESIGN FIRES: PERFORMANCE-BASED DESIGN IN FIRE AND STRUCTURES

Fires can occur in almost any location of a building and of any severity through out the life-span of a building. It is therefore impossible to consider every fire, which may occur, during the design stage of a project. This makes choosing the worst case realistic design fire scenarios probably the largest challenge in a performance-based fire design. No definite answers but only guidance can be given to the design engineers as every building will have its unique features and usages, which need to be considered. Therefore the below shall help the designers but cannot replace experiences and thorough engineering judgment and sensitivity analyses in selecting the appropriate design fire scenarios.

Once the design fire scenarios are selected the characteristics of the design fires have to be determined. The design fires can be based on simple equations, parametric fires, zone models, Computational Fluid Dynamics simulations or experimental fire data.

Finally, the heat transfer from the fire to the structural members is an important and often overlooked step in structural fire engineering. The heat transfer becomes particularly important in the cases of localised fires rather than fully developed compartment fires.

Design Fire Scenarios

Design fire scenarios should be chosen in a way that each aspect of fire safety is tested thoroughly. The design fire scenarios should include different locations and types of fire to create a worst case, but still realistic, condition for whatever part of fire safety is assessed.

The International Fire Engineering Guidelines suggests in Chapter 1.2.11 a two stage approach for the selection of the design fire scenarios. The first step is to determine the potential fire scenarios, which will take into account factors such as:

- The nature, quantity, arrangement and burning behaviour of combustibles in each enclosure.

- Enclosure geometry

- Number of enclosures and their relationship

- Connection between enclosures

- The fire protection measures in the building and their effect on the fire.

The second step is then to select the worst case realistic design fire scenarios, which will be analysed, from the list of possible fire scenarios. "*Usually, a number of severe scenarios which have a reasonable probability of occurrence and significant potential for loss (life, property, etc.) are selected for analysis. Care and judgement should be used to avoid unnecessarily analysing events with a very low probability of occurrence, but where the scenario may have vey high adverse consequences, due consideration should be given if not in the primary analysis at least in the sensitivity studies.*"

NFPA 5000-09 Section 5.5 gives a good overview of the selection of design fire scenarios and provides a number of "required" design fire scenarios designed to test and challenge the fire safety of a building. It is the opinion of the author that not all of the "required" design fire scenarios given in NFPA 5000 have to be analysed in detail but that by using a Qualitative Risk Assessment the relevant scenarios for the building in hand can be selected.

BS7974 and PD7974 Part 0 also give a good introduction to the process of determining the appropriate design fire scenarios.

The different scenarios should also consider that individual parts of the fire safety systems are not working in during a fire (i.e. sprinkler systems not activating, smoke extract not activating). Which and how many of the systems are assumed to not activating is a function of the reliability of the system and the consequences caused by the system failure.

References:

Australian Government, State and Territories of Australia, 2005, International Fire Engineering   Guidelines - Edition 2005, ISBN 1 74161 456 2.

National Fire Protection Association, 2008, NFPA 5000- Building Construction and Safety Code – Edition 2009.

British Standards Institution, 2001, Application of fire safety engineering principles to the design of buildings – Code of Practice, ISBN 0 58038 447 0.

British Standards Institution, 2002, Application of fire safety engineering principles to the design of buildings – Part 0: Guide to design framework and fire safety engineering procedures, ISBN 0 580 40 169 3.

Design Fires

After the design fire scenarios have been decided the next challenge is to determine the appropriate design fires. A design fire is a simplified but still representative description of the complex physical and chemical processes occurring in a fire. Design fires can either be constant over time, called steady-state fires, or changing with time, called transient fires. Design fires can be split into two different types namely compartment fires and localised fires. A third relatively newly described type of design fire is a so called travelling fire. Design fires are normally described as either the heat release rate versus time (localised fires) or the gas temperature versus time (compartment fires).

For compartment fires in normal buildings EN1991-1-2 gives the Standard Fire Curve, t^2-fires and the parametric fire curves, which consider the fire load density, the ventilation conditions and the thermal properties of the compartment boundaries. The parametric fire curves also include the cooling phase of a fire. Recently, alterative parametric fire curves have been published in Germany and will be implemented into the German National Annex as replacement of the parametric fire curves in Annex A EN1991-1-2.

For a more complex description of compartment fires, multi-zone fires can be used to calculate the gas temperatures. A number of zone models have been programmed and are available via the internet. The most commonly used ones are CFAST and OZONE. However, when zone models are used for the design of structural elements the effects of the radiation from the fire to the structure should be considered additionally to the results of the zone models, which normally only give the gas temperature of the smoke layer.

The most complex way of fire modelling is the use of computational fluids dynamics with a combustion model. However, due to the complexity of this type of analysis it is not discussed further in this contribution. Nevertheless, the author would like to note that that CFD analysis should be used very carefully, when used in fire safety design and sufficient sensitivity studies should be undertaken to ensure a robust solution. A recent Round-Robin study on the Dalmarnock fire test demonstrated the large scatter and the unreliability of CFD in the prediction of a compartment fire. However, CFD modelling is frequently used to determine the spread of smoke in large spaces and atria.

For all design fires representing a compartment fire it is important that different ventilation conditions are taken into account to consider the effects of windows breaking during the fire.

The second group of fires considered here are localised fires. They range from sprinkler controlled fires over fires in large open spaces to external fires and are also called pre-flashover fires if they occur in an

enclosure. If the conditions are right flashover could occur and a localised fire could develop into a compartment fire.

Localised fires have been subject to significant amounts of research and design equations have been developed. Localised fires are typically described by a heat release rate (HRR), a fire base area, a perimeter or shape of fire base, a flame height, a flame temperature, which is changing along the length of the flame and a radiative fraction. Some of the parameters of a localised fire need to be selected based on what is expected to burn and other can be calculated. The relevant equations can be found amongst other places in PD7974 Part 1, the SFPE Handbook 3rd Edition Chapter 02-01 and 02-02 or in *An Introduction to Fire Dynamics* by Dougal Drysdale.

As input data for the calculation of a localised fire it is possible to use experimental fire data of a similar fire scenario possible in the building of consideration. Experimental fire data should always be used in combination with a safety factor. There is a considerable amount of fire test data available for individual items tested in cone calorificmeters as well as whole room assemblies and cars. Some of this data can be found in the on the NIST webpage on fire, the BRE Design fire database or the SFPE Handbook 3rd Edition Chapter 03-01. Furthermore, BRE368 gives design fires for smoke control systems.

In a building fitted with an automatic sprinkler system the most common fire will be a sprinkler controlled fire due to the high reliability of sprinklers. In most cases a fire would be suppressed or even extinguished by a sprinkler system. However, a conservative assumption is that the sprinklers would only control the fire spread beyond the item of fire origin. The heat release rate versus time curve for such a sprinkler controlled design fire can be represented based on a t^2-fire, the fire load density, the heat release rate per unit area, the assumption that if 70% of the fire are consumed the decay phase of a fire starts and finally a tool to predict the activation and response time of the sprinkler system. The data is all available from EN1991-1-2 and as a sprinkler activation tool the FPE-tool developed by NIST can be used, which gives the maximum HRR of the sprinkler controlled fire. When the sprinkler activation time is calculated it should be based on the activation of the 5th sprinkler head.

The last type of design fires is a travelling fire. This type of fire could occur in a large compartment commonly used in open plane office environments. The compartment is too large for a codition right for a flashover to develop and so the fire remains a localised fire which is moving throughout the entire compartment with different speeds and areas engulfed at the same time depending on how much fire load is available and how fast the fire load is consumed. Such a fire could be a critical design case for the structure as the heating and cooling of the structures occurs at the same time relatively close to each other.

A good summary of design fires and a lot of other very useful information for structural fire engineering can be found on the One-Stop-Shop webpage developed by the University of Manchester.

References:

European Committee for Standardisation, EN1991-1-2: 2002. Eurocode 1: Actions on structures: Part 1-2: General Actions - Actions on structures exposed to fire.

Zehfuss, J.; Hosser, D. A parametric natural fire model for the structural fire design of multi-storey buildings, Fire Safety Journal 42 (2007) 115 – 126.

Zehfuss, J.; Hosser, D. Vereinfachtes Naturbrandmodell für die Brandschutzbemessung von Bauteilen und Tragwerken. Bauphysik 27 (2005), Heft 2, S. 79-86.

http://cfast.nist.gov/

http://www.argenco.ulg.ac.be/logiciel_EN.php

G. Rein, J.L. Torero, W. Jahn, et al., Round-Robin Study of a priori Modelling Predictions of The Dalmarnock Fire Test One, Fire Safety Journal 44 (4), pp. 590-602.

British Standards Institution, 2003, Application of fire safety engineering principles to the design of buildings – Part 1: Initiation and development *of fire within the enclosure origin (Sub-system 1)*, ISBN 0 58041 195 8.

The SFPE Handbook of Fire Protection Engineering, Third Edition, NFPA, 2002, ISBN 0 87765 451 4.

Drysdale, D., An introduction to Fire dynamics, 2nd edition, John Wiley & Sons Ltd. 1998, ISBN 0 47197 290 8.

http://www.fire.nist.gov/fire/

http://projects.bre.co.uk/frsdiv/designfires/

BR 368, Design Methodologies for Smoke and Heat Exhaust Ventilation', Building Research Establishment, 1999.

http://www.bfrl.nist.gov/866/fmabbs.html

http://www.mace.manchester.ac.uk/project/research/structures/strucfire/Design/performance/freModelling/default.htm

Jamie Stern-Gottfried, J., Law, A., Rein, G., Gillie, M. and Torero, J.L., 2010, *A Performance-based Methodology Using Travelling Fires for Structural Analysis*, Proceedings from the 8th Conference on Performance-Based Codes and Fire Safety Design Methods

Heat transfer from fire to structure

The transfer of heat from a fire, a plume or a smoke layer to an object is dominated by radiation and convection. A list of useful references on this topic is given below:

References:

SFPE Handbook 3rd Edition Chapter 01-03 and 01-04

Sparrow, E.M., & Cess, R.D., Radiation Heat Transfer, 1978.

A CATALOG OF RADIATION HEAT TRANSFER CONFIGURATION FACTORS (http://www.me.utexas.edu/~howell/tablecon.html#C2)

TNO Methods for the calculation of physical effects – due to releases of hazardous materials (liquids and gases) 3rd Edition – Chapter 6

SFPE Standard on Calculating Fire Exposures to Structures (http://www.sfpe.org/Technical/Committees/FireExposures.aspx)

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PROCEDURAL METHOD OF APPLICATION OF ENGINEERING METHODS IN GERMANY

Introduction

Germany is a federal state with 16 federal states, called "Bundesländer". As the building law is regulated by the federal states there are 16 different building codes in Germany.

Fortunately the building codes are similar, but there are some specific distinctions. However the material requirements in the building codes are the same. They depend on the height of the building. The basis of the requirements is the well-known standard-time-temperature curve which rises infinitely and comprises all fires in building constructions. Whereas natural fires have a different lapse, after achieving their peak they decline when the fire load is mostly consumed.

Material requirements in German building codes

- **R 30** for buildings h <= 8 m

- **R 60** for buildings h <= 13 m

- **R 90** for buildings h > 13 m
  and special buildings

- For common design of steel
  elements usually
  cost-intensive
  fire protection materials
  needed
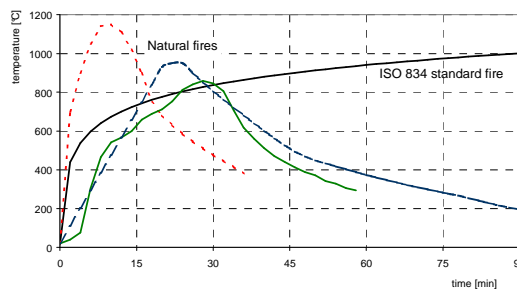
Figure 1: Comparison Material requirements based on ISO 834 and natural fires

Fire protection has a high significance in Germany and German building law.

This may have historical reasons as the terrible fires in German cities with half-timbered houses in 1800's e.g. in Hamburg and in World War II. Thus the following safety targets in the German building codes are established:

- Prevention of fire and smoke spread

- Enabling rescue of persons and animals

- Enabling of fire fighting

Fulfillment of safety targets

Basically there are two ways for the fire safety design (Zehfuss 2007). The regular way is the prescriptive design, the second way is the performance-based design which is applied only for special complex buildings such as airports, stations, big assembly halls etc.

In prescripitive design the material requirements for fire resistance are concretized (e. g. REI 90 for slabs between storeys) or combustibility of building materials.

This is the regular way of doing fire safety design.

Performance-based design requires approval of the building authority.
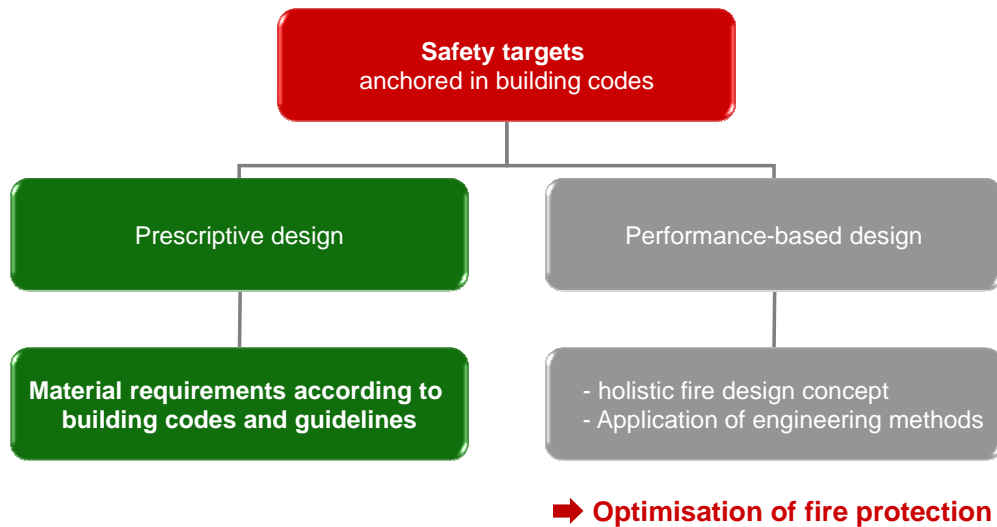
Figure 2: Two ways of fulfillment of safety targets

Structural fire safety design with Eurocodes

The application of the performance based method is a deviation of the building code. Thus performance based design requires emphatic approval of the building authority and the fire brigade. The performance based design of construction elements is conducted by Eurocodes. In Germany annex A, E and F of Eurocode 1-1-2 was not accepted by building authorities. The National annex which is to be published in December 2010 replaces informative annexes of Eurocode 1-1-2.

The national annex contains:

- Annex AA Simplified natural fire model for fully-developed compartment fires,
- Annex BB Input data for application of natural fire models (including a new safety concept),
- Annex CC (informative) Checking and validation of calculation programs for fire safety design by advanced calculation methods.

Annex AA

The parametric temperature-time curves of Eurocode 1-1-2, annex A in some cases provide an unrealistic temperature increase and decrease. One reason is that for fuel-controlled fires in residential and office buildings the maximum temperature is fixed at a fire duration of 20 minutes. For fire compartments with large openings and an enclosure with low thermal conductivity the Eurocode gives an extremely fast enhancement and decay of the temperature. For fire compartments with small openings and an enclosure with high thermal conductivity however an extremely slow decay of the temperature is assumed. The parametric temperature-time curves in Eurocode 1-1-2 only describe the fully-developed phase of the fully-developed fire without considering the growth phase of the fire. Results of fire tests with ordinary furnishings reveal that even in small fire compartments it can take some minutes to reach the fully-developed fire from the initial fire. The most critical point is that the parametric temperature-time curves of Eurocode 1-1-2 Annex A have no temporal connection with the rate of heat release of Eurocode 1-1-2 annex E.

This deficiency with respect to temperature increase and decrease shall be clarified by comparing the parametric temperature-time curve according to Eurocode 1-1-2 with the recorded average temperature-time curve of the NFSC2 fire test No. 2 at BRE governed by fuel-controlled conditions (Zehfuss 2007). Even more obvious is the discrepancy between the temporal course of the parametric temperature-time curve

and the rate of heat release according to Eurocode 1-1-2 annex E. The latter reaches its maximum after 30 minutes and declines after 43 minutes. The parametric temperature-time curve and rate of heat release neither match with each other nor are they temporary congruent.
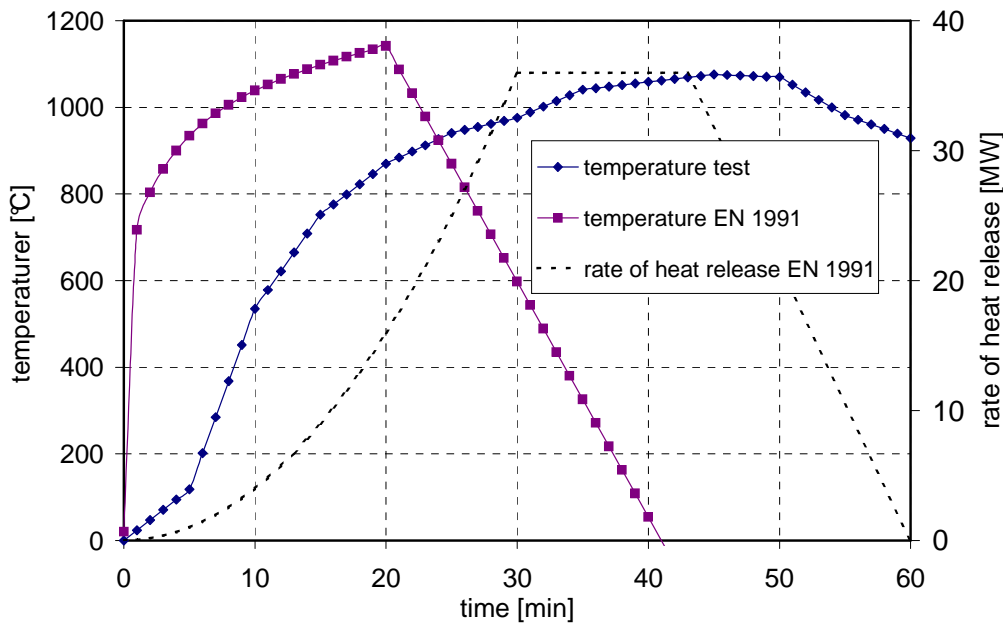
Figure 3: Temperature-time curve and heat release rate according to Eurocode 1-1-2

For annex AA parametric fire curves were developed which are based on the approach of the rate of heat release, temperature-time curves were simulated with the zone model CFAST for various boundary conditions vs influencing factors. Hosser (2007) illustrates the qualitative shapes of the rate of heat release and the upper layer temperature computed with CFAST. The temporary link between the curves is evident. Both curves can be characterized by three distinctive points at the times t_1, t_2, t_3, where the slope of the curves is changing. From the beginning of the fire until t_1 the rate of heat release rises quadratically and the upper layer temperature increases rapidly. At t_1 the maximum rate of heat release is achieved and remains constant until t_2. After t_1 the upper layer temperature increases moderately. As 70 % of the fire load is consumed at t_2, the rate of heat release drops off linearly. Achieving its maximum at t_2 hence the upper layer temperature declines. At t_3 the complete fire load is consumed and the rate of heat release decreases to 0. At this time the upper layer temperature-time curve bends and declines slower than before.

The times t_1, t_2, t_3 can be determined by the consideration of the functional course of the rate of heat release. For the total description of the run of the upper layer tem-perature-time curve the associated temperatures T_1, T_2 and T_3 have to be ascertained (Hosser 2008). Being aware of the characteristic times and temperatures, the course of the temperature can be described functionally as parametric fire curves. Thus, the parametric fire curves of annex AA are a simplified description of the upper layer temperature-time curve of a natural fire. They can serve as a realistic thermal action for the structural fire design avoiding the application of sophisticated heat balance models.
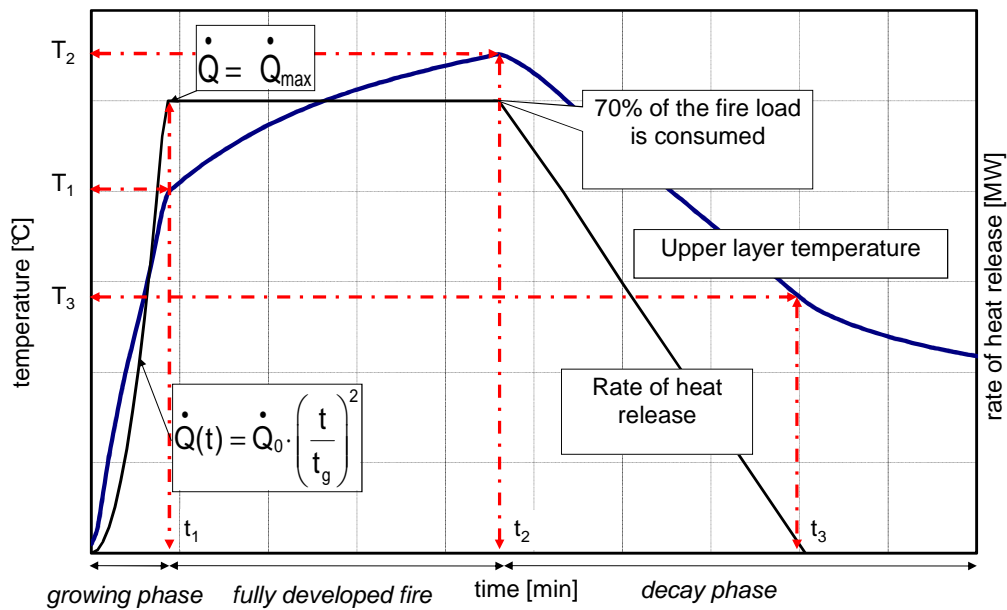
Figure 4: Approach of the rate of heat release and the corresponding upper layer temperature (principle)

Annex BB

The German National Annex BB to Eurocode 1-1-2 contains a new safety concept which will replace the informative Annex E of Eurocode 1-1-2. The safety concept of Eurocode 1-1-2 annex E was not accepted by the German building authorities due to the questionable mathematical foundations and the multiplicative connections of up to 10 partial safety and reduction factors. The multiplication of the probability of dependent measures is mathematically incorrect.

In the German National Annex BB to Eurocode 1-1-2 design values of the fire load $q_{f,d}$ in buildings with different use and design values for the maximum rate of heat release for different design fire scenarios are defined. The given design values of the affecting factors on the effects of fire consider the required reliability of structural members and global structures in the accidental event of a fire according to the comprehensive safety concept (Hossser 2008, Schaumann 2010). For these two design values the respective partial safety factors $\gamma_{fi,q}$ and $\gamma_{fi,\dot{Q}}$ have to be determined in dependency of the respective reliability index β_{fi} as given by Schaumann (2010).

$$\beta_{fi} = -\Phi^{-1}\left(p_{f,fi}\right)$$

where

$p_{f,fi}$ accepted target conditional probability of failure in case of fire,

Φ^{-1} inverse normal distribution

The probability $p_{f,fi}$ is given by:

$$p_{f,fi} = \frac{p_f}{p_{fi}}$$

where

p_f accepted target probability of failure in case of fire (e. g. $p_f = 1{,}3 * 10^{-5}$ for medium damages);

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p_{fi} probability of occurrence of a fully developed fire

The probability of occurrence of a fully developed fire p_{fi} is given by:

$$p_{fi} = p_1 \cdot p_2 \cdot p_3$$
where

p_1 probability of occurance of an initial fire in a compartment per year,

p_2 probability of failure of manual fire defense,

p_3 probability of failure of fire protection measures.
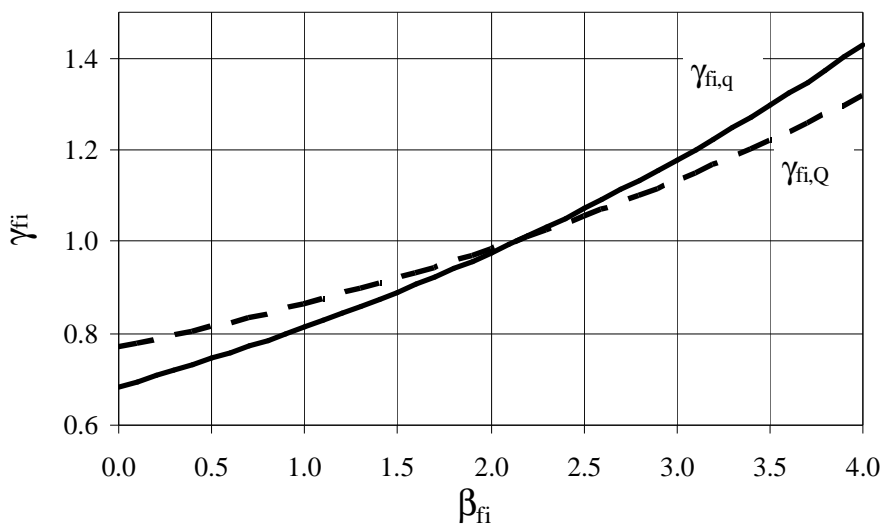
Figure 5: Partial safety factors versus reliability index according NA BB to Eurocode 1-1-2

Annex CC

The physical, mathematical and mechanical foundations of calculation software for structural fire safety design with advanced calculation methods in Eurocode have to be validated considering the thermal and mechanical analysis. Due to this reason the German annex CC to Eurocode 1-1-2 has the target to inspect the application of calculation software for structural fire safety design by means of validation examples. Therefore the application of the software for the design of real structures can be assessed.

With the validation examples single steps of the structural fire safety design can be validated by definite assessment criteria. For this purpose the computational accuracy of the software is checked for the concerning assessment criteria. In an assessment-array the existing analytical solution or the results of simulations approved programs for the particular validation example are listed. With it the results of the inspected simulation software can be compared. The deviation has to be inside the permissible tolerances.

The collection of validation examples contains examples concerning the heating and cooling of elements, the thermal elongation, thermal stresses and the load bearing and deformation behaviour of elements under fire conditions.

Realised Projects

In the following building projects the performance-based fire safety design is adopted by hhpberlin fire safety engineers:

   – Alstertal shopping centre, Hamburg (steel construction garage),

- Berlin Central station (steel construction)
- Eurobahnhof, Saarbrücken (existing reinforced concrete slabs),
- National Convention Centre, Hanoi (steel construction),
- Willy Brandt International Airport Berlin (steel construction),
- Frankfurt/M International Airport (prestressed concrete beams),
- Volksbank Arena, Hamburg (steel construction),
- Balastas Dambs Property high rise tower Riga (facade construction),
- Headquarter adidas, Herzogenaurach (steel construction),
- Ostkreuz station, Berlin (steel construction).

Summary

In this contribution the fire design practice in Germany for performance-based structural fire safety design is described which is conducted by the Eurocodes and the national annexis. In the German national annex to Eurocode 1-1-2 a new simplified natural fire model (parametric fire curves), a new safety concept and validation examples for simulation software are published with which structural fire safety design on an adequate safety level can be achieved.

References:

Zehfuss, J.; Hosser, D.: A parametric natural fire model for the structural fire design of multi-storey buildings. Fire Safety Journal 42 (2007) 115-126.

Zehfuss, J.; Hosser, D.: Vereinfachtes Naturbrandmodell für die Brandschutzbemessung von Bauteilen und Tragwerken. Bauphysik 27 (2005), Heft 2, S. 79-86 (in German)

Hosser, D., Weilert, A., Klinzmann, C., Schnetgöke, R.: Development of a safety concept for fire safety design applying engineering methods acc. to Eurocode 1 Part 1-2 (Erarbeitung eines Sicherheitskonzeptes für die brandschutztechnische Bemessung unter Anwendung von Ingenieurmethoden gemäß Eurocode 1 Teil 1-2). Final report DIBt-research project ZP 52-5-4.168-1239/07. iBMB, TU Braunschweig, June 2008 (in German)

Schaumann, P.; Sothmann, J.; Albrecht, C: Safety concept for structural fire design – application and validation in steel and composite construction. Proceedings of the 11th International Symposium on Fire Protection at Leipzig. vfdb (Verein zur Förderung des Deutschen Brandschutzes e.V., German Fire Protection Association), 2010.

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TRAVELLING FIRES IN LARGE COMPARTMENTS

Close Inspection of real fires in large, open compartments reveals that they do not burn simultaneously throughout the whole compartment. Instead, these fires tend to move as flames spread, partitions or false ceilings break, and ventilation changes through glazing failure. These fires have been labelled 'travelling fires' and represent a new understanding of fire behaviour in modern building layouts.

Despite these observations, fire scenarios currently used for the structural fire design of modern buildings are based on traditional methods that come from the extrapolation of existing fire test data. Most of this data stems from tests performed in small compartments that are almost cubic in nature. This test geometry allows for good mixing of the fire gases and thus for a uniform temperature distribution throughout the compartment [4].

While this behaviour is different from that observed in real fires, it has generally been deemed a conservative, and therefore appropriate, approach for structural fire design, in the absence of better and more relevant data. However, although this approach might be considered acceptable for most design cases, the need for better optimisation of structural behaviour in fire will eventually require a more realistic definition of the fire.

Computational methods for determining structural behaviour have matured over the last decade and have enabled analysis of more complex structural systems. This has led to an understanding that many modern structures do not behave in the same manner as simpler, more traditional frame based systems. In order to address these differences, and continue to enable innovation in structural design, a more sophisticated characterisation of fire scenarios is required.

This article describes a new methodology to produce detailed fire scenarios accounting for travelling fires that are consistent with the requirements of analysis of modern structural systems and contemporary architectural features.

It is important to understand the context of the current design methods to establish this new methodology. Traditionally, structural fire analysis has been based on one of two methods for characterising the fire environment:

the standard temperature-time curve (as specified by various standards, such as BS 476: Fire tests on building materials and structures, ISO 834: Fire resistance tests – Elements of building construction, and ASTM E119: Standard test methods for fire tests of building construction and materials)

parametric temperature-time curves (such as that specified in EN 1991-1-2: 2002: *Eurocode 1. Actions on structures. Actions on structures exposed to fire*)

While both of these methods have great merits and represented breakthroughs in the discipline at their times of adoption, it is recognised that they have limitations.

The standard temperature-time curve, which is used as the basis for the fire rating system in most building codes and standards worldwide, was first published in 1917. The curve came from collating various fire tests into one idealised curve. The tests that fed into the development of the standard fire were intended to represent worst-case fires in enclosures, so that the structure could withstand burnout. However, these tests were conducted, and the standard fire created, prior to much scientific understanding of fire dynamics. Thus, the standard fire, unlike a real fire, has a relatively slow growth period; never reduces in temperature due to fire decay; and is independent of building characteristics such as geometry, ventilation and fuel load.

The next major landmark for structural fire analysis, in terms of design, was a guidance document produced in Sweden in 1976. This work incorporated the current understanding of compartment fire dynamics based on tests conducted in small-scale enclosures. The guide presented the key factors of compartment fire temperatures as the fuel load, ventilation and the thermal properties of the wall linings. It gave design recommendations and a series of temperature-time curves for a wide range of critical parameters, accounting for the cooling period of the fire.

The Eurocode parametric temperature-time curve is based on the same fire science as the Swedish design guide. The Eurocode temperature-time curve was developed to collapse all of the curves given in the Swedish guidance document into a simplified mathematical form.

Eurocode 1 states that the design equations for the parametric temperature-time curve specified are only valid for compartments with floor areas up to 500m^2 and heights up to 4m. In addition, the enclosure must have no openings through the ceiling and the thermal properties of the compartment linings must be within a limited range. As a result, common features in modern construction, such as large enclosures, high ceilings, atria, large open spaces, multiple floors connected by voids, and glass façades, are excluded from its range of applicability. These limitations, which are largely associated with the physical size and geometric features of the experimental compartments on which the methods are based, ought to be carefully considered when the method is applied to an engineering design beyond the recommended ranges of applicability. This is particularly relevant given the large floor plates and complicated architecture of modern buildings.

It is noted that PD 6688-1-2:2007: *Background paper to the UK National Annex to BS EN 1991-1-2* suggests that designers can ignore the Eurocode 1 limitations on floor area and compartment height, and can expand the range of the compartment lining values. However, while this allows engineers to use the equations on more practical applications, it does not appear to address the observed travelling nature of real fires in large compartments.

A travelling fire is when only a portion of a floor plate is fully involved in flames that then move to other areas of the floor as burnout occurs in locations of earlier burning. The fire travels as flames spread to unburned fuel, partitions or false ceilings break, and ventilation changes through glazing failure.

Over the last decade, there have been several real, large fires where fires were observed to travel across floor plates and between floors. These fires include those in the World Trade Center Towers 1, 2 and 7 in New York in September 2001; the Windsor Tower in Madrid, Spain in February 2005; and the Faculty of Architecture building at TU Delft in the Netherlands in May 2008. All of these fires led to some form of structural failure.

This concept of travelling fires is in direct contrast to the basis of current design methods, which assume uniform conditions throughout the compartment for the entire duration of burning. A fire that burns uniformly within a large enclosure would generate high temperatures, but only for a relatively short duration. However, a fire that travels will still create elevated temperatures away from the fire (the far field), as well as flame temperatures in the near field (*see Figure 1*). A travelling fire can therefore inflict the structure with elevated temperatures for longer durations.
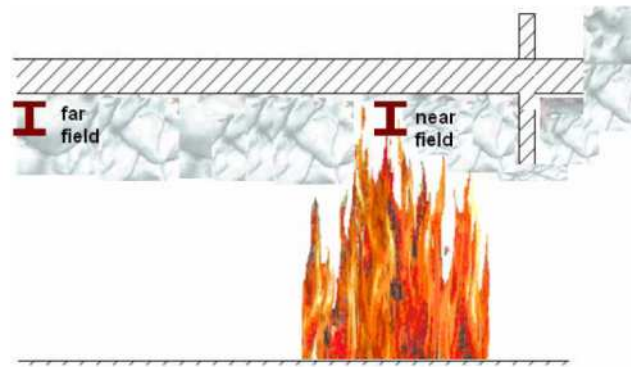
Figure 1: Illustration of the near and far fields in a large compartment fire.

Due to the discrepancy between fire behaviour in actual incidents and the assumed fire behaviour in traditional design methods, it is possible that current practices for structural design do not consider a potentially worst-case fire scenario. Non-uniform heating across a compartment floor could cause a failure mechanism in the structure, which may not occur if uniform temperatures were applied to the structure. For example, a cool, unheated bay in a multi-bay structure could produce high axial restraint forces, and that could result in failure of a heated element.

In most situations, however, traditional design methods may be overly conservative, compared to the impact of a real fire. Therefore, it is beneficial to have a methodology that can incorporate the actual dynamics of a travelling fire into structural analysis, to better enable structural and architectural design innovation.

There is currently no approved guidance to assist structural fire engineers in quantifying travelling fire behaviour for structural analyses.

A new methodology is currently being developed at the University of Edinburgh [3, 4] that allows for a wide range of possible fires, including both uniform burning and travelling fires, by considering the fire dynamics within a given building. This methodology has two unique characteristics when compared to the traditional methods:

- more than one fire is considered – that is, a full 'family' of fires is investigated, with each fire having a different area of burning

- the methodology divides the effect of a fire on structural elements into the near field and the far field

By considering a range of fires, instead of just one, and splitting the effect of a fire into the near and far field, instead of just one uniform field, this methodology allows the full range of possible fires to be considered. This is important because the exact nature of a fire that may challenge a structure cannot be known during the design phase of a building.

The family of fires can be selected by taking a range of fire sizes, expressed in terms of percentage of floor area burning. For example, a small fire might be 1% of the total floor area and the largest possible fire is 100% of the floor area. Because the burning rate of such large fires tends to be nearly uniform, the burning time for a fire in a given area is the same, regardless of the size of the area. This burning time is typically around 15-20 minutes for typical office fuel loads [3, 4]. For example, assuming a fuel load of 600MJ/m^2, a 1MW fire burning over 2m^2 would take 20 minutes to burn out. A 20MW fire burning over 40m^2 would also take 20 minutes to burn out. These burn out times are consistent with observations of the World Trade Center fires.

Due to this uniform burning, a fire that simultaneously covers 100% of the floor area would burn out in about 20 minutes, as it is area independent. A fire that involves 1% of the floor area would burn out locally

in about 20 min, but then continue to burn as it travels throughout the compartment. Thus, this small fire would last more than 30 hours in a 2,000m² floor plate. Clearly, these are extreme values, but the various fire sizes between the two cover the full range of total fire durations physically possible.

Once the full range of fire sizes has been identified, the characteristics of the near field and the far field of each fire can be determined. The near field is simply the floor area of the fire, and the far field is the remainder of the floor. The near field temperature is that of the flames, usually around 1,200°C. The far field temperature varies with distance from the fire and can be affected by specific building geometry, such as atria. The far field temperature distribution can be determined from various fire engineering tools, such as hand calculations computational fluid dynamics models.

Passing on the full temperature variation of the far field to a structural model could be prohibitively cumbersome. Therefore a single, averaged fire temperature is used in this methodology.

Once this procedure has been followed, the temperature-time curve for any given structural element can be determined. A generic example of this is given in Figure 2, where:

T_{nf} is the near field temperature

T_{ff} is the far field temperature

T_{∞} is the ambient temperature

t_{pre} is the time after ignition but before the fire arrives

t_b is the time the fire burns locally at the element being examined

t_{post} is the time after the fire has travelled past the element
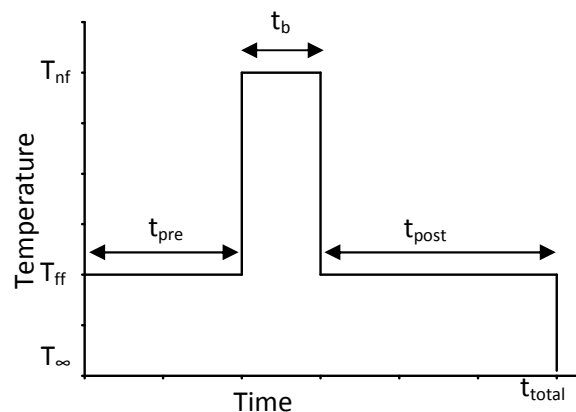
Figure 2: Temperature-time curve at a structural element in one area of a compartment during a travelling fire.

The growth and decay phases are assumed to be much faster than the burning time and thus are neglected from the curves. Note that, while the growth and decay phases are assumed to be fast in the gas phase, the resulting structural steel or concrete temperature-time curves will have noticeable periods of growth and decay, due to their thermal inertia.

Determining both t_{pre} and t_{post} is dependent on the path of the fire and the exact position of the structural element being examined. However, it is not possible or practical to establish a fire's path of travel *a priori* to a real incident; therefore assumptions must be made for worst-case conditions. Clearly, many paths of fire travel are possible, and the sensitivity of this parameter on the structural response is one aspect of the methodology to be explored and developed further.

An example of the resulting set of far field temperatures for a full family of fires is given in Figure 3. The results are for a single floor of a large building with a 2,000m^2 floor area and 3m floor to ceiling height. The façade of the building is completely glazed.
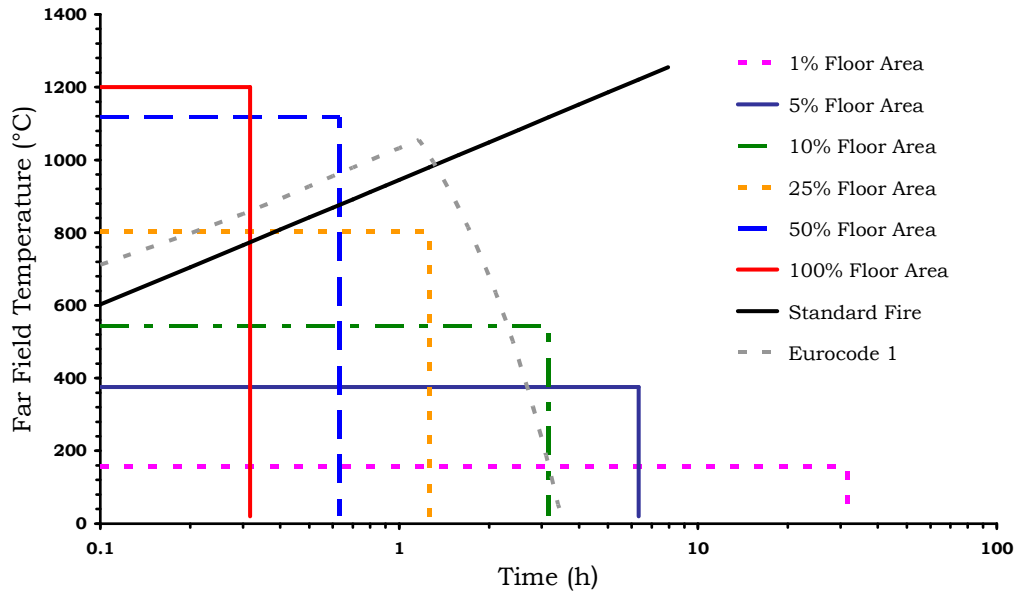
Figure 3: Far field temperatures for a range of fires and the traditional methods [4]

The temperatures shown in Figure 3 are for the far field only. Any one structural element subjected to a specific fire will experience a curve that includes both far field and near field temperatures, like that given in Figure 2. The curves for the standard fire and the Eurocode 1 parametric temperature-time curve do not make this distinction – their temperature-time curves are for a single, uniform temperature for the entire compartment. Note that the case of a fire covering 100% of the floor area is a uniform fire (the near field and the far field are the same).

The temperature-time curves generated by this new methodology can be used as inputs to structural analysis tools for areas of interest. The curves produced allow structural engineers to calculate structural steel or concrete temperatures and the resultant structural response with their current design tools. This new methodology also facilitates the collaboration between fire safety engineers and structural fire engineers, which is an identified need within the structural fire community[7], to jointly determine the most challenging fire scenarios for a structure and its subsequent behaviour.

The traditional design methods for thermal inputs for structural analysis are known to be valid for small enclosures. However, observations of real fires in large, open compartments indicate that fires tend to travel through a floor plate.

This new methodology, based on the concept of travelling fires in large enclosures, has already been applied to real buildings for initial case studies. While further development of the methodology is needed, progress is being made to better characterise the fire environment of large enclosures. In addition, by enabling fire safety engineers and structural fire engineers to work together to better understand the structural behaviour of a building due to fire, the methodology will help ensure more optimisation and innovation in structural and architectural design.

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Pettersson, O., Magnusson, S-E. and Thor, J., Fire Engineering Design of Steel Structures, Publication 50, Swedish Institute of Steel Construction, 1976.

Rein, G., Zhang, X., Williams, P., Hume, B., Heise, A., Jowsey, A., Lane, B. and Torero, J., Multi-story fire analysis for high-rise buildings, Proceedings of the 11th International Interflam Conference, 2007, http://www.era.lib.ed.ac.uk/handle/1842/1980.

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Gann, R.G. et al, Reconstruction of the fires in the World Trade Center Towers, NIST NCSTAR 1-5, 2005.

McAllister, T.P. et al, Structural fire response and probability collapse sequence of the World Trade Center Building 7, NIST NCSTAR 1-9, 2008.

Buchanan, A., The challenges of predicting structural performance in fires, the 9th International Symposium on Fire Safety Science, Germany, 2008.

J Stern-Gottfried, A Law, G Rein, M Gillie, JL Torero, A Performance-based Methodology Using Travelling Fires for Structural Analysis, 8th International Conference on Performance-Based Codes and Fire Safety Design Methods, Lund University, Sweden, June 2010. http://www.see.ed.ac.uk/~grein/rein_papers/Stern-Gottfried_SPFE2010.pdf

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DESIGN FIRES: PROBABILISTIC APPROACH

Overview

Evaluation of the fire load separately for each considered fire compartment is very ardous and not always effective. For this reason its nominal value is usually estimated only in relation to each specific type of compartment utility, based on the attainable statistical data. In professional literature one can find a large number of specialistic reports and articles in which the results of fire load measurements are collected and discussed for various kinds of fire compartment. Furthermore, the influence of the arrangement of potential fuel as well as of compartment geometry on the energy and intensity of resulted fire is there widely studied.

Recommended literature:

Yii H. W., Effect of surface area and thickness on fire loads, Fire Engineering Research Report, 2000/13, March 2000, University of Canterbury, New Zealand, ISSN 1173-5996.

Statistical distribution of fire load

Statistical data collected for given, considered type of fire compartment are treated as the random variables, decribed by means of Gumbel probability distribution. This type of distribution has been chosen as the best approximation of the real data distribution resulting from the histogram, because of the significant skewness coefficient. The modal value of the fire load is then specified as well as the Gumbel standard deviation, connected with this value, is also computed. As a result of such mathematical modelling the design value of the fire load is defined as the upper fractile of Gumbel probability distribution when the acceptable probability of its upcrossing is fixed as 20% (the levels 10% and 5% are also recommended in some papers). Furthermore, the differentiated level of the probability of fire occurrence and various range of fire protection measures applied in considered compartment can be taken into account in the analysis owing to the multiplication of the value of design fire load by additional partial safety factors evaluating failure consequence and/or untypical conditions of the exploitation of structural members.

Recommended literature:

Schleich J. -B., The design fire load density qfd function of active fire safety measures, the probabilistic background, JCSS Workshop "Reliability based code calibration", Zurich, Switzerland, 2002,

Schleich J. -B., Performance-based design for the fire situation, theory and practice, Nordic Steel Construction Conference, Malmoe, Sweden, 2009.

Fire loads

Probabilistic model applied for the specification of design value of the fire load, proposed by J.-B. Schleich, is verified by many authors. Exemplarily the fire load is studied in detail in France for the compartments localised in shoping centers, hotels and hospitals. On the other hand, this load is precisely analysed for many industrial and commercial buildings in Switzerland. There is also a large number of results of fire load measurements originating from Canada. In this case the fire load characterising compartments enclosed within commercial establishments such as restaurants, bookstores and shoe stores was examined in detail. Consequently, the lognormal probability distribution has been proposed to fire load description as the better alternative in relation to the application of Gumbel probability distribution.

Recommended literature:

Thauvoye Ch., Zhao Bin, Klein J., Fontana M., Fire load survey and statistical analysis, Proceedings of 9th IAFSS Symposium, Karlsruhe, Germany, 2008,

Hadjisophocleous G., Zalok E., Development of design fires for performance-based fire safety designs, Proceedings of 9th IAFSS Symposium, Karlsruhe, Germany, 2008.

Design fire

The design fire is defined, for which not only the characteristic of potential fire is looked for, according to the fire load density as well as the compartment geometry and ventillation possibility, but also the real safety level is taken into consideration by means of the application of reliably calibrated partial safety factors. These factors are most frequently connected with fire protection measures which are possible to use in particular case of fire, with the opportunity to improve the professional firefighting action, with accesibility of the building for fire brigade, with the number and technical condition of escape routes etc. Many of such factors are calibrated only based on the experience and statistical estimation, without more complex probabilistic analysis. Some of them are recommended to use by the standard EN 1991-1-2.

Recommended literature:

Schleich J.-B., Performance-based design for the fire situation, theory and practice, Nordic Steel Construction Conference, Malmoe, Sweden, 2009,

Hietaniemi J., Mikkola E., Design fires for fire safety engineering, VTT Working Papers 139, Finland, 2010.

Risk of ignition

The probability of fire occurrence may be calculated in more reliable way by means of the application of the model of Poisson process. The quantification of the risk of fire ignition, interpreted as the parameter of process intensity, should be formally adopted. This approach gives the opportunity to estimate such probability even if the attainable data are incomplete.

Recommended literature:

Lin Yuan-Shang, Estimations of the probability of fire occurences in building, Fire Safety Journal, 40, 2005,

Ryden J., Rychlik I., A note of estimation of intensities of fire ignitions with incomplete data, Fire Safety Journal, 41, 2006.

Mathematical models

There are many mathematical models helpful in the estimation of the risk of fire expansion from one fire compartment to another. In general they are based on the analysis of the specific networks with suitable logical gates types "OR" and/or "AND". The technique adopted from the study of classical Bayesian networks seems to be the best approach to reliably assess the probability which is looked for.

Recommended literature:

Fitzgerald R. W., Building Fire Performance Analysis, John Wiley & Sons Ltd., Chichester, England, 2004,

Holicky M., Schleich J.-B., Modelling of a structure under permanent and fire design situation, Proceedings of the International Conference "Safety, Risk, Reliability – Trends in Engineering", Malta, 2001,

Cheng Hao, Hadjisophocleous G., The modelling of fire spread in buildings by Bayesian network, Fire Safety Journal, 44, 2009.

Safety levels

In general the safety level evaluated for the case of fire is the result of many factors which are connected between each other in a complex and intercorrelated network. Analysis of such network has to take into consideration its internal hierarchy and structure. Furthermore, the importance of particular factors is not known in advance. For this reason multicriterial analysis is necessary to obtain the reliable value of failure probability. The modern techniques of the study, originating from the classical decision theory, are proposed to be used in this field.

Recommended literature:

Zhao C. M., Lo S. M., Lu J. A., Fang Z., A simulation approach for ranking of fire safety attributes of existing buildings, Fire Safety Journal, 39, 2004,

Ginda G., Maślak M., Assessment of factors influencing the fire safety for building users, Proceedings of IABSE Symposium "Responding to Tommorow's Challenges to Structural Engineering, Budapest, 2006, IABSE Report, Vol. 92.

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SOME LIMITS TO COMPUTATIONAL MODELLING OF ENCLOSURE FIRE DYNAMICS

Modelling is among the fastest developing areas in fire safety science. The validation of fire models is an essential task for the advancement of fire safety engineering. The large majority of the studies that have compared simulations to experiments have found them in reasonable agreement. However, most of these simulations were conducted after the tests took place and with good access to the recorded experimental data (this is known as a posteriori modelling). Thus, the comparisons are not blind and the modelling may include some bias due to prior knowledge of the evolution of the event.

In blind simulations, also called a priori, the modeller is provided only the description of the initial scenario and is responsible for developing the appropriate input from this description. The modeller has no access to the experimental measurements of the event and thus is providing a true forecast. Most fire model validations are open simulations, also called a posteriori, where the modeller is also provided with the results from the experiment. Only a priori simulations are free of the bias that could be introduced by prior knowledge of the development of the event.

This paper is a summary of the more detailed work by Rein et al. 2009 and Rein et al. 2007. The objective of the study is to compare the modelling results produced a priori by different teams of modellers of a realistic fire scenario, the Dalmarnock Fire Test One. Test One is part of the Dalmarnock Fire Tests series of fire experiments (Abecassis Empis et al. 2007, Rein et al. 2007), conducted in 2006 in a real high-rise building. The results are compared to the experimental measurements to allow evaluation of the accuracy and reliability of the a priori process as a whole.

The present round-robin study involves a pool of participants composed of independent international teams, all working in the field of fire engineering and using fire modelling as part of their professional practice. There are representatives from most branches of fire modelling, from fundamental and applied research to final engineering design.

The Dalmarnock Fire Tests

The large-scale Dalmarnock Fire Tests consist of tests conducted in a 23-storey reinforced concrete building in Glasgow (UK), July 2006. The two tests of main interest here (henceforth referred to as Test One and Test Two) were those conducted in two identical flats. The Dalmarnock Tests were set up to recreate a realistic fire scenario involving multiple fuel packages arranged in an ordinary fashion, consistent with real dwellings. Arrangements of this type invariably result in fire growth that is not readily obvious and thus prediction of fire development can be a challenge.

Test One was held in a two-bedroom single family flat, with the living room set up as the main experimental compartment. Test Two was conducted in an identical flat but two floors below Test One. An identical fuel arrangement was used in both tests. Both fires grew to flashover conditions but only Test One was allowed to continue burning during post flashover. A detailed description of the compartments, the fuel layout and the measurements has been given by Abecassis-Empis et al. (2008) and Rein et al. (2007, Chp 2), but an overview is included here for quick reference.

The flat comprised a main corridor off which were two bedrooms, a bathroom and a living room, with a small kitchen. The main experimental compartment was the 3.50 m by 4.75 m, 2.45 m high living room, with a 2.35 m by 1.18 m set of windows on the west-facing wall. It was furnished as a regular living room/office. The general layout was such that most of the fuel was concentrated towards the back corner (NE) of the compartment, away from the window and the doors, with a fairly even fuel loading throughout the rest of the compartment (see Figure 1) and no further loading elsewhere in the flat.

While the main source of fuel was a two-seat sofa stuffed with retardant flexible polyurethane foam, the compartments also contained two office desks with a computer and a padded chair each, as well as three tall wooden bookcases, a short plastic cabinet, three small wooden coffee tables, a range of paper items and two tall, plastic lamps. Figure 2a) shows a photograph, taken before the test. The fuel load density was estimated to be 32 kg/m2 of wood equivalent, whereas a typical value for office buildings is around 25 kg/m2. The ignition source was a plastic wastepaper basket filled with crumpled newspaper and approximately 500 ml of heptane. It was placed in-between the sofa and a bookcase. During Test One all the doors in the flat were left open. Windows of all compartments, excluding the kitchen and one bedroom, were left closed.
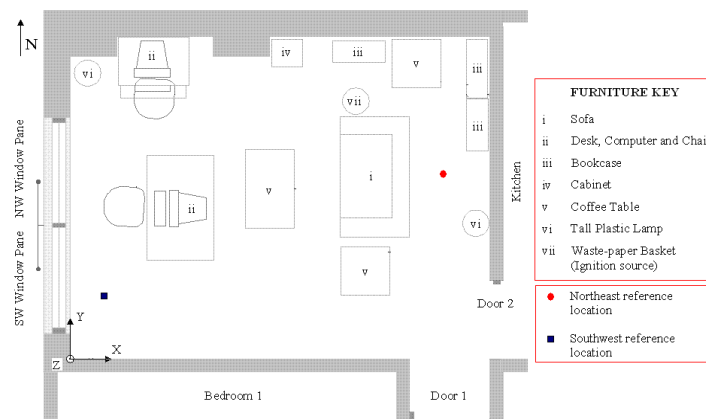
Figure 1: Furniture layout in the main compartment [Abecassis-Empis et al. (2008) and Rein et al. (2007)]

Figure 2: View of the ignition source, the sofa and nearby items in the main compartment: a) before the fire; and b) after the fire [Abecassis-Empis et al. (2008) and Rein et al. (2007)].

A large number of sensors were installed throughout the flat in order to obtain detailed measurements of the fire development. More than 270 thermocouples were distributed throughout the main compartment to provide gas temperature data at high spatial resolution suitable for comparison with computational fluid dynamics (CFD) simulations. Smoke obscuration was measured using 8 pairs of laser-receiver sensors. Gas velocity was measured at the ventilation openings of the main compartment using 14 bi-directional velocity probes. Additionally, more than 15 video cameras, spread throughout the flat, provided visual recordings. Other measurements include temperatures within and heat fluxes to the east wall and the ceiling of the main compartment, a dozen smoke detectors in different rooms, and strain and deflection gauges used to monitor the deformation of structural elements.

Test Two had an identical flat geometry and fuel configuration. The only two significant variations were a smaller amount of heptane used for the ignition and a drastically altered ventilation conditions. Despite these drastic differences, the Test Two fire was seen to spread following the same pattern as Test One.

Both tests show an almost identical time to flashover (only 10 s difference). Although both tests did not produce identical fires the differences are relatively small, and it shows that the Dalmarnock compartment test configuration provided a robust and reasonably repeatable fire scenario for benchmarking.

Round-Robin Study

The aim of the study was the forecast of fire dynamics for the set scenario. The teams were asked to forecast the test results as accurately as possible, and to avoid an engineering analysis with conservative assumptions or safety factors, as is common for use in fire safety design. All teams were given access to a common pool of information about the test experimental setup and initial conditions. This included: the geometry and dimensions of the flat; a detailed and measured layout of the room furniture; 50 photographs of the whole compartment final set-up, windows, fuel packages and instrumentation; and individual descriptions, material, dimensions and photographs of each furniture item. A replica of the sofa and the wastepaper basket were tested separately, under laboratory conditions, and the initial heat release rate of the ensemble was measured in the furniture calorimeter. In total, ten simulations were submitted: eight CFD simulations using FDS4, and two simulations using zone model CFAST. More information and detailed descriptions of each input file are provided in Rein et al. 2009 and Rein et al. 2007.

Comparison and analysis of the results

The global heat release rate (HRR) is given in Figure 3. The same legend is used for the results in all the subsequent figures. Three distinct stages are observed: initial growth, first post flashover stage until compartment window breakage, and subsequent second post-flashover stage. The heat release rate inside the main compartment was calculated during the test using the principle of oxygen depletion. The HRR measurements convey an approximately steady 3 MW fire between the onset of flashover (at 300 s) and the compartment window breakage at 800 s. Thereafter the HRR is around 5 MW until forced extinction.
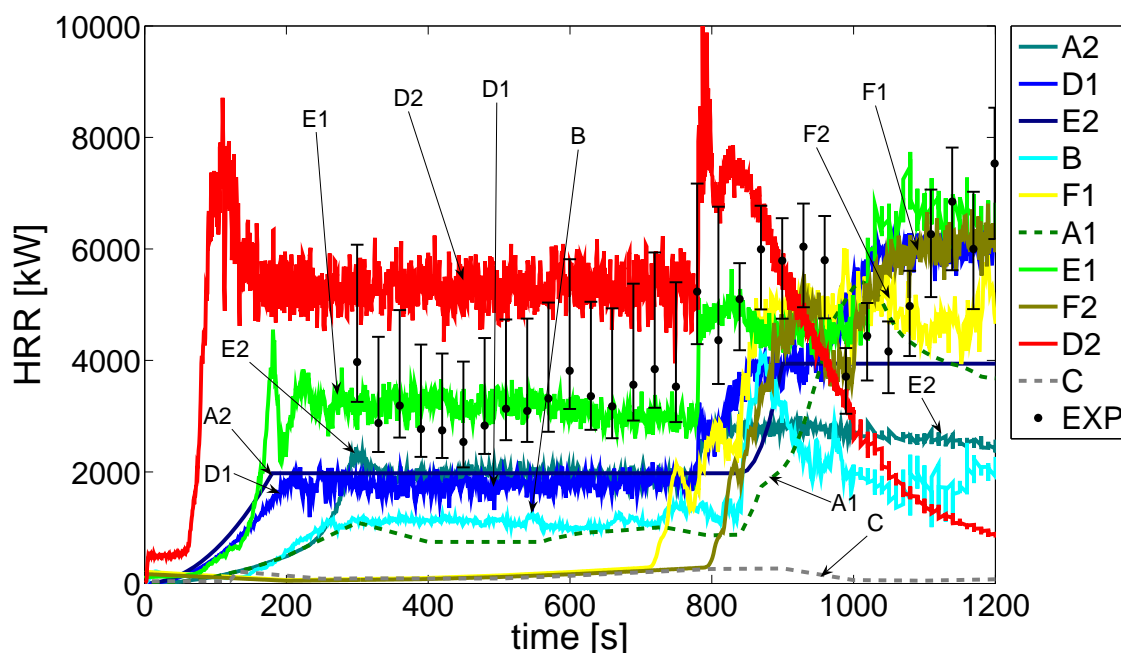
Figure 3: Evolution of the global heat release rate within the compartment.

The simulations show a wide scatter of predicted fire behaviours. One simulation (D2) over-predicts the HRR by 100 %, another (E1) provides a reasonably good prediction and all other simulations under-predicted the HRR in the range of 30 % to 90 %. The best average results and lowest scatter are obtained after the forced window breakage (at 800 s), as the teams were informed of the timing of this event. The HRR curve is the single most important and comprehensive characteristic of fire development, resulting from the time evolution and coupling of many important fire mechanisms.

Figure 4 left) shows the evolution of the average hot layer temperature and Figure 4 right) shows the hot layer height. The experimental values are averaged over the entire layer. There is a wide scatter of modelling results shown in both figures. Most simulations under-predicted the hot layer temperature.
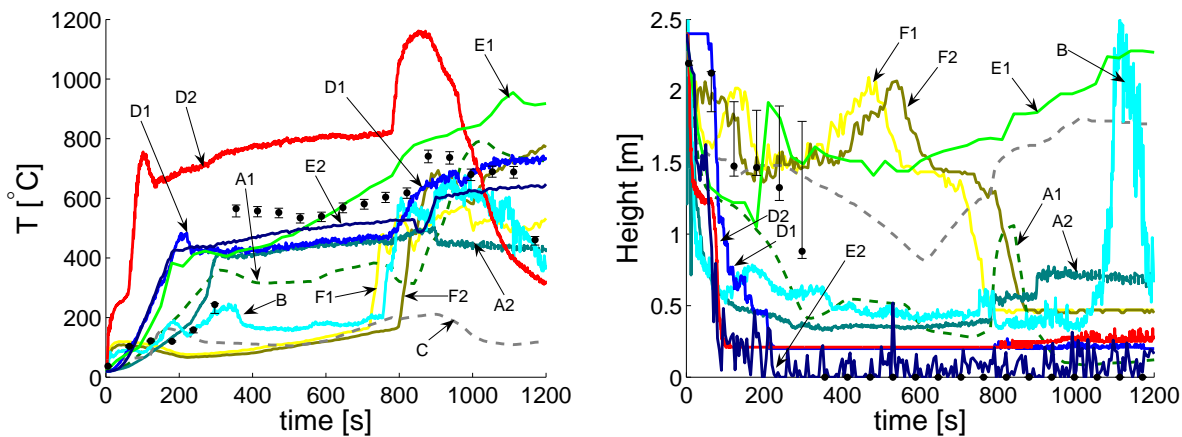
Figure 4: Left) Evolution of the average temperature of the hot layer in the compartment. Right) Evolution of the hot layer height to from compartment floor.

Discussion and Conclusions

A realistic and repeatable fire test was conducted under conditions that are particularly relevant to CFD modelling validation. The study is an assessment of the state-of-the-art of fire modelling in a non-trivial, realistic scenario and evaluates the process of fire modelling as a whole. The results indicate large scatter and considerable disparity, both amongst the predicted fires and between the predicted fires and the experimental data. The scatter of the simulations is much larger than the estimated experimental error. The scatter is also much larger than the expected experimental variability. The results show that current modelling cannot provide good predictions of HRR evolution (i.e. fire growth) in realistic complex scenarios.

The greatest source of scatter originates in the prediction of the fire growth – i.e. the heat release rate. This is due to the inherent complexity in fire growth modelling, particularly for flame spread and ignition of secondary fuel items. Since most participants used the same fire model, FDS4, it is reasonable to think that the wide range of predicted behaviour is mostly the result of the uncertainty associated with the definition of valid input data under the constrains of the model.

The aim of the round robin exercise was to forecast the test results as accurately as possible, and not to provide an engineering analysis with conservative assumptions or safety factors. Design for fire safety was not the objective of the exercise. The issue of how to use reliably fire modelling for safety and engineering design is a very important issue that currently under research by many institutions and firms.

References:

Abecassis-Empis, Reszka, Steinhaus et al., Characterisation of Dalmarnock Fire Test One, Experimental Thermal and Fluid Science 32 (7,) pp. 1334-1343, 2008.

Rein, Abecassis-Empis, Carvel (Eds), The Dalmarnock Fire Tests: Experiments and Modelling, The University of Edinburgh, ISBN 978-0-9557497-0-4, November 2007. Accessible at

http://www.era.lib.ed.ac.uk/handle/1842/2037

Rein, Torero, Jahn, et al. Round-Robin Study of a priori Modelling Predictions of The Dalmarnock Fire Test One, Fire Safety Journal 44 (4), pp. 590-602, 2009. doi:10.1016/j.firesaf.2008.12.008. Copy available at http://hdl.handle.net/1842/2704

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NOTE ON DESIGN FIRES IN STRUCTURES, COMPARMENTS AND TUNNELS

Heat Release Rate (HRR) is commonly accepted as the most important parameter in characterizing fires. The HRR can be calculated according to European standard EN 1991-1-2; however, it is often difficult to quantify the HRR. In some countries it is not possible to use Annex E where HRR is defined due to the size of the compartment and the type of occupancy. In cases where relevant data is not available, it is nowadays possible to use modelling and fire simulation to assess the heat release rate. Accurate prediction of fire growth and spread on the bases of the physical properties of the fire room and the combustibles is beyond the capability of any present fire-simulation software. It is possible to make conservative assessment how large fire may propagate within the given space.

Heat release rate in EN 1991-1-2

EN 1991-1-2 describes the thermal and mechanical actions for the structural design of buildings exposed to fire. Fire load densities and heat release rate are in Annex E.

The definition of the possible fires that can occur as well as concept of potential hazard and fire severity are expressed by the aid of fire load which is based on the amount of energy that would be available if all the fuel were to be consumed. In Annex E the amount in mean of heat released by a fire per unit of time (HRR) is based on different occupancies. Important points of HRR curve are described. The maximum of heat release rate is the first important point. The decay phase starts when 70% of the total fire load has been consumed and completed when the fire load has been completely burnt. In case of ventilation controlled fire the curve has to be extended.

References:

EN 1991-1-2. 2002 Eurocode 1: Actions on structures- Part 1-2:General actions- Actions on structures exposed to fire. CEN: Brussels

Heat release rate and fuel packages

The simplified approach of design fire characterisation that is based on the concept of fuel packages is described. This concept utilises the fact that our empirically based knowledge on initial fires is sufficient for the time evolution of the initial fire and, that the advanced fire simulation programs such as the FDS can extrapolate the fire spread from the initial fire to secondary igniting objects.

The fuel packages are a source of heat and their rate at which they release heat is based on heat release rate (HRR) experimental data (in this approach heat release rates depend on the usage of the building). This approach guarantees a safe side assessment in full analogy the live load design values. Assessment of fire growth and spread is based on the capability of the FDS fire simulator to make conservative estimations how rapidly and how large a fire may grow.

References:

Hietaniemi J.: Fuel Packages for Structural Fire Safety Design, Natural Fire Design, VTT Technical Research Centre of Finland, 2007

Hietaniemi J., Mikkola E.: Design Fires for Fire Safety Engineering, VTT Technical Research Centre of Finland, 2010, ISBN 978-951-38-7479-7

Heat release rate in road tunnel fires

The use of computer simulation models for the fire safety design of tunnels has been increasing over the past few years. This increase has been attributed to many factors including the complexity of tunnel networks, the need for a better understanding of fire behaviour in tunnels because heat and toxic combustion products cannot be dissipated out of the tunnel as compared to an open environment. While using computer modelling in fire safety design enables designers to build a computational model that represents the system for analysis of fire dynamics, smoke movement and to test performance of their design, most of these models require the input of HRR by the user. Two methodologies to estimate the HRR in a tunnel considering tunnel geometry and ventilation conditions were compared: a statistical approach, which is a simple and quick calculation method, and a numerical approach using Fire Dynamics Simulator 4.0.7 (FDS4). The discussion in this work evolves around estimating the HRR involving a single light goods vehicle (LGV) fire carrying wooden pallets and factors that could possibly affect the analysis.

References:

Cheong M. K., Spearpoint M. J., Fleischmann C. M.: A Comparison of a Statistical and Computational Fluid Dynamics Approach to Estimate Heat Release Rate in Road Tunnel Fires, Fire Technology, 46, 531–549, 2010, DOI: 10.1007/s10694-009-0105-9, The United States, 2009

Ingason H.: Design fire curves for tunnels, Fire Safety Journal 44 (2009) 259-265, Elsevier Ltd. 2008

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SMOKE CONTROL

It is of primary importance to understand the phenomena of smoke production and propagation in buildings and to develop smoke management systems or strategies because smoke is the first cause of death in case of fire.

- The objectives and basic principles of smoke management systems are explained.

- The fire plume phenomenon is briefly exposed and fire plume models are cited.

- The most important design tools for smoke management systems are finally detailed.

Smoke hazard

Smoke is the first cause of death in case of building fires. Life safety hazards from smoke include mainly:

- Toxic gases.

- Reduced visibility.

- High temperatures.

- Reduction of oxygen concentration.

Smoke is also an important cause of damage to buildings and in particular to building finishing.

It is therefore of primary importance to understand the phenomena of smoke production and propagation in buildings and to develop smoke management systems or strategies.

References:

G.D. Lougheed, Basic Principles of Smoke Management for Atriums - Construction Technology Update No. 47, Dec. 2000.

Smoke management system: objective and principles

The main objective of a smoke management system is to maintain a tenable environment within exit access and area of refuge access paths for the time necessary to allow occupants to reach an exit or area of refuge.

The smoke management systems are various and can be based on one or several of the following principles:

- Natural smoke filling of an unoccupied volume or smoke reservoir

- Mechanical smoke exhaust capacity to remove smoke from a space

- Gravity smoke venting

- Maintaining pressure differences across smoke zone boundaries

References:

NFPA 92B, Guide for smoke management systems in malls, atria, and large areas. National Fire Protection Association, Quincy, MA, 2009.

Fire plumes

When a mass of hot gases is surrounded by colder gases, the hotter and less dense, mass will rise upward due to the density difference, or buoyancy. This phenomenon happens above a burning fuel source. The buoyant flow is referred to as a fire plume, see Figure 1. Cold air is entrained by the rising hot gases, causing a layer of hot gases to be formed below the ceiling.

Different analytical expressions of the properties of fire plume have been proposed by several authors. Four of them (Drysdale, 1999; Karlsson and Quintiere, 2000) are :

- Heskestad plume model;

- Zukoski plume model;

- McCaffrey plume model;

- Thomas plume model.
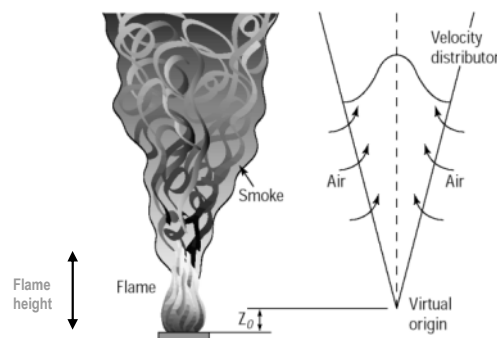
Figure 2: Fire plume and associated schematic model

The plume models are used to estimate the quantity of smoke produced by a localised fire and can be used in hand calculation or two-zone models (see next section).

References:

Drysdale, D., An introduction to fire dynamics. New York: Wiley, 1999. ISBN-10: 0471972916
    Karlsson, B., Quintiere, J. G., Enclosure Fire Dynamics, CRC Press 2000. ISBN: 0849313007

Design tools

- There are several possibilities to model the smoke movement within a building. Some of the most widely used models are:

- pre-flashover analytical fire models (see previous section – plume models) ;

- numerical models:

- two-zone models;

- computational fluid dynamic models.

Zone models

The main hypothesis in zone models is that the compartment is divided into zones where each zone has a uniform properties (temperature, species concentrations...) distribution at any time. In two-zone models, there is a hot gas layer which is close to the ceiling and a cold gas layer which is close to the floor.
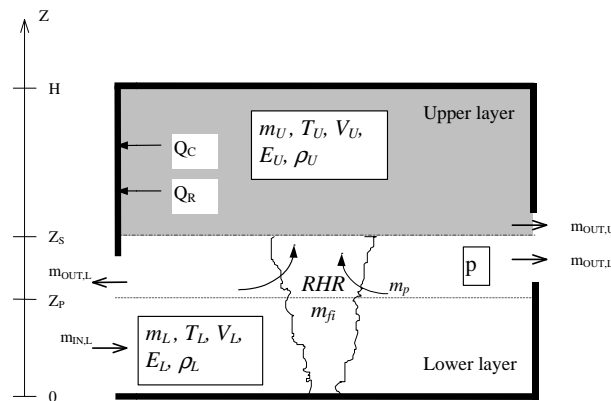
Figure 3: Two-zone model principles

These models have been developed specifically to design smoke control systems.

Computational fluid dynamics (CFD) models

This type of model is used in many engineering disciplines and is based on a time dependent and three-dimensional solution of the fundamental conservation laws. The partial differential equations of the thermodynamic and aerodynamic variables (Navier-Stokes equations) are solved in a very large number of points in the compartment. These equations are usually solved by finite volume method.

These models are used to solve many types of problems involving fluid movements. There are now more and more used to design smoke control systems.

a.   b.
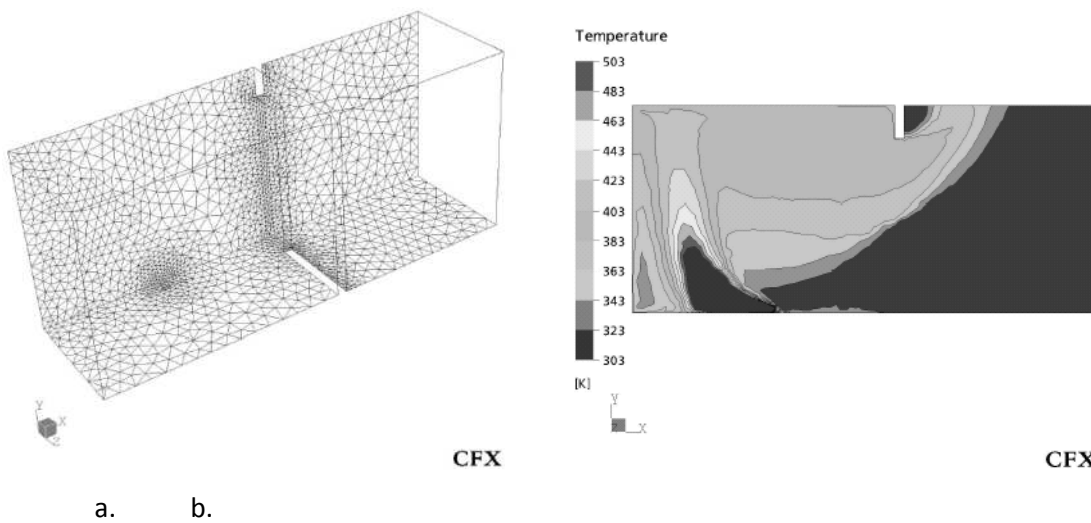
Figure 4: CFD modelling of a compartment fire a. Isometric view of the surface mesh on the symmetry plane and floor. b. temperature on the symetry plane (Sinai 2003)

References:

Cadorin, J-F., Compartment fire models for structural engineering, ULg, 2003, ISSN 0075-9333. Sinai, Y., Validation of CFX-5 against a Steckler fire experiment,CFX-VAL15/0103, AEA Technology, 2003.

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TENABILITY CONDITIONS

Toxic species in fire gas effluents

Toxicity is measured as the dose of a gas that will lead to death or incapacitation (often known as untenable conditions). About 75% to 80% of fire victims are not touched by flame but die as result of exposure to smoke, exposure to toxic gases or oxygen depletion. These life-threatening conditions can result from burning contents, such as furnishings, as well as from the materials involved.Most of the modern applications for polymeric materials (both natural and synthetic) contain carbon and hydrogen, in addition some contain nitrogen, sulphur and halogens. Carbon containing materials release CO and CO2 in various concentrations depending on the amount of air available to the combustion process. CO2 has a synergistic effect on CO in terms of toxic uptake as concentrations above 5% cause hyperventilation. Furthermore those materials containing nitrogen, sulphur and halogens produce hydrogen cyanide (HCN), nitrogen oxides (NOx), sulphur dioxide (SO2), ammonia (NH3) and halogen acids (HCl, HBr and HF) respectively.

Assessment of toxic hazards.

It is impossible to determine exact concentrations that will cause death or incapacitation, but table below gives some typical values (in parts per million, ppm) for these events and which are often used as the basis for tenability levels in fire safety codes.The early experiments established lethal toxic potency,LC50 (orLD50), as the concentration of combustion products required to cause immediate death in 50% of the rats exposed to smoke over a specific period of time(30 minutes) in a small scale laboratory tests . However, this 'definitive' measurement has a number of flaws, in particular it's failure to take into account other manifestations of toxicity poisoning effecting response behaviour prior to death. The COSHH (COntrol of Substances Hazardous to Health regulations) procedure allows the maximum exposure for people to escape from a fire alive to be predicted rather than the present procedures of predicting the exposure levels in fires that will cause death.15 minutes is a typical exposure time to toxic gases in large fires and this is considered a realistic basis for fire toxicity to be assessed in terms of safe evacuation. COSHH is part of statutory law in the EU.

Toxic Gas		15 Min Exposure limit COSHH (ppm)	Toxic Gas		15 Min Exposure limit COSHH (ppm)
Carbon Monoxide	CO	200	Formaldehyde	CH_2O	2
Nitric Oxide	NO	35	SO2	SO_2	5
Nitrogen Dioxide	NO_2	5	HCl	HCl	5
Hydrogen Cyanide	HCN	10	Ammonia	NH_3	35

Table : Main Toxic Gas Concentration Limits ppm (COSHH)

References: EH 40/2005 workplace exposure limits 'containing the list of workplace exposure limits for use with the Control of Substances Hazardous to Health Regulations 2002(as amended)', HSE Books, UK Health and Safety Executive.

Toxic Gases in simulated aircraft interior fires using FTIR analysis

An aircraft interior fire is a closed room fire scenario with a fixed ventilation rate of 20-30 air changes per hour. Experimental fires were undertaken in a closed room fire test facility for 22 air changes per hour.

Three fire loads were investigated: modacrylic blankets, head rest cushions and a lifejacket, together with some other items provided by the aircraft operators to passengers. A Temet heated FTIR was used to determine the toxic emissions for 60 species every 5s in the fires. The analysis included acidic gases such as acrolein, acetic and formic acids as well as HCl and HCN, where extremely high levels were measured in the first two fires. The source of HCl was concluded to be pyrolysis of the halogenated fire protection material on the blankets. In all cases levels of formaldehyde were very high. The source of HCN was the acrylic material in the blankets and this also gave very high fuel NOx formation together with significant ammonia. Without the blankets present the lifejacket fire was much lower in HCl and HCN and formaldehyde and SO_2 were the main toxic problems. In terms of the overall toxicity CO was not the main problem. These results indicate significant problems of toxic gases in the early stages of fires in aircraft.

References:

Andrews *et al*, 'Toxic Gases in simulated aircraft interior fires using FTIR analysis'. Proc. 5th International Colloquia on Explosions in Reactive Systems, Edinburgh, April, 2007.

FTIR Investigations of Toxic Gases in Air Starved Enclosed Fires

Toxic gases in air starved fires in small rooms with modern fire doors and heat insulation, where the ventilation flow areas are very small, were simulated in a 1.57 m3 fire enclosure with 2.7 air changes an hour. Three fires were investigated: kerosene and diesel pool fires and a pine wood crib fire and all had a similar total heat release. The results showed that air starved fires developed slowly with low fire temperatures and overall lean mixtures. CO levels were relatively low and FTIR analysis of 21 toxic gases showed that aldehydes, acrolein, acetic acid, SO_2, NO_2 and some toxic hydrocarbons had a combined toxicity that was greater than that due to CO. The wood fire had particularly high acrolein, aldehydes and acetic acid levels. The toxicity of the complex mixture of fire toxic gases was assessed using the COSHH 15 min. exposure limit as the reference limiting toxic concentration.

References:

Andrews *et al.*, 'FTIR investigations of toxic gases in air starved enclosed fires' in: 8th International Symposium Proceedings 18-23 September, 2005, Beijing, China18-23 September, 2005, Beijing, China, pp.1035-1046. 2005.

Toxic Gas Measurements Using FTIR for Combustion of COH Materials in Air Starved Enclosed Fires

Pine wood cribs and folded cotton towel fires were investigated for 1 - 40 air changes per hour. The results show that very low ventilation cotton fires generated toxic gases at higher levels than those for wood, but for higher ventilation the wood fires were more toxic. Both fires exhibited a slow smouldering combustion phase at low ventilation rates and toxic gases were high throughout this period. The COSHH 15 minutes toxicity assessment method gave that Acrolein, formaldehyde and CO were the major toxic gases in all the fires.

References:

Andrews *et al.*, 'Toxic Gas Measurements using FTIR for Combustion of COH Materials in Air Straved Enclosed Fires' in: European Combustion Meeting, Crete, 2007.

Thermal behaviour and toxic emissions of flame retarded timber in Fire enclosure tests

Timber in different forms contributes as first and secondary ignited material to the initiation and spreading of fires in industrial buildings. The aim of this work was to investigate experimentally the fire behavior of

wooden surfaces treated or not with flame retardants in a 1.57 m3 fire enclosure linked to the FTIR analyzer in well ventilated conditions (75kg/h) that are usually encountered in industrial activities when large metal doors, ramps, ventilation opening etc are open in order to serve the process of production. Seven (7) wooden crib fires were investigated using untreated pine wooden cribs or treated at different percentage (%) of the total surface area with a water – based, flame retardant intumescent, suitable for internal surfaces. In most fully-treated (100%F.R.) cases, even in a half-treated (50% F.R.) case, lower or almost equal to unity emissions were measured compared with the bare samples. This can be explained, in such cases, due to the fact that during the intumescent action, there was either 'no ignition' of the samples (100% F.R. -treated cases), or a considerable ignition delay occured (50% F.R. -treated case). Excessive HCN and NOx occurred in 60% untreated cases due to the considerable involvement of the flame retardant paint in flaming combustion, since it contains N in its chemical composition.

References:

D.Tsatsoulas, "Thermal behaviour and toxic emissions of flame retarded timber in Fire Enclosure tests",Seventh International Conference on 'Risk Analysis 2010', pp 295-306, 13-15 September, Algarve, Portugal.

Thermal behaviour and toxic emissions of various timbers in Cone Calorimeter tests

Eight species of wood typically employed in floors, ceilings, shelves, pallets, packing cases, scaffolding, furniture etc., were selected for experimental investigation. The samples were subjected to constant incident heat fluxes of 35, 50, 65 and 80 kWm-2 in a Cone Calorimeter linked to a FTIR analyzer. "Significant" acrolein peak values are measured for all samples. Samples with a facing layer (melamine in particular), which are known to have a chemical flame retardation reached higher peak values of CO, HCN and NH3 during combustion.

References:

D.Tsatsoulas, H.N.Phylaktou and G.Andrews. 'Thermal behaviour and toxic emissions of various timbers in Cone Calorimeter tests'. In the proceedings of 'First International Conference on Disaster Management and Human Health Risk ', pp181-194, 23 -25 September 2009, New Forest, UK.

Thermal behaviour and toxic emissions of flame retarded timbers in Cone Calorimeter tests

Eight (8) species of wood treated or not with three (3) typical intumescent flame retardants were subjected to constant incident heat fluxes of 35, 50, 65 and 80 kWm-2 in a Cone Calorimeter linked to the FTIR analyzer. In the cases of flame retarded samples, where there was 'no ignition' or a considerable ignition delay of the samples (35 and 50 kWm-2) there were similar or less toxic emissions compared to the bare samples. NH3 was an exception, since both flame retardants contained ammonium in their chemical composition, which was released during the intumescent action of the samples. As irradiance increases, increasing values of toxic emissions by volume are seen during flaming combustion. Excessive toxic emissions by mass are also seen as irradiance increases.

References:

D.Tsatsoulas, 'Thermal behaviour and toxic emissions of flame retarded timber in Cone Calorimeter tests'. International Journal of Safety and Security engineering. Accepted paper at 10 of Jule 2010.

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THE HEAT TRANSFER ALONG A STEEL BAR

Statement of the problem

The analysis presented here studied the longitudinal heat transfer in a steel element submitted to a stepwise variation of the incident flux along its length. The goal of the study was to establish whether the longitudinal fluxes must be taken into account or can be neglected in a real analysis.

The mesh

The amount of energy received per unit length is proportional to the exposed area Am. The amount of material to be heated per unit length as well as the longitudinal heat flux are proportional to the area of the section. The section factor Am/V will thus be the representative parameter. If the thermal gradients on the section are not considered, it is sufficient to analyse a 2D bar, the thickness of which is meshed using a single finite element. Three section factors were considered: 80m-1, 250 m-1 and 400 m-1. Since the section factor is defined as the ratio between the area of the exposed surface and the enclosed volume i.e. the perimeter of the section and its surface, in our case the section factor is (see Figure 1):

$$A_{m/V} = \frac{l}{l \cdot t} = \frac{1}{t}$$

where:

      l is the length of the bar,

      t is the thickness of the bar,

leads to the three heights considered: 1/80 = 0.0125 m, 1/250 = 0.004 m, and 1/400 = 0.0025 m.
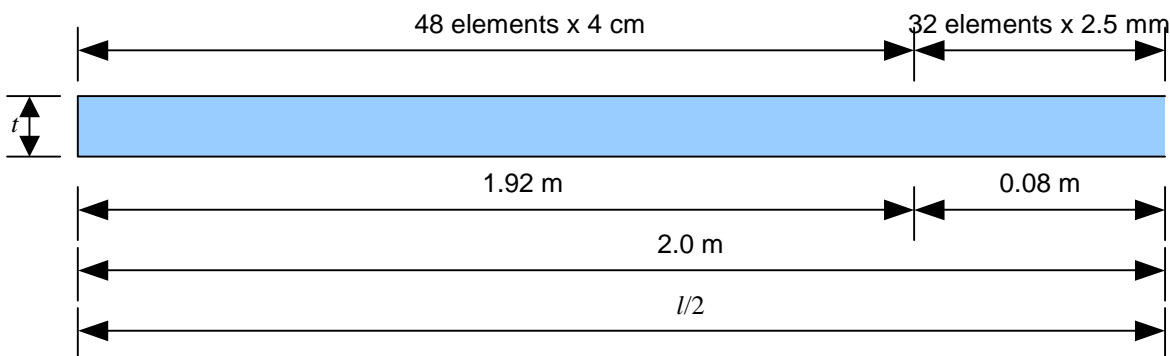
Figure 1: The mesh of the rod

For the mesh, the SAFIR SOLID elements types were used which are four nodes rectangular finite elements used in thermal analysis. The thermal properties of the steel were those from ENV 1993-1-2.

The protection

Each of the three cases was computed using a protected and non protected solution. The thickness of the protection material was 20 mm.

The protection considered was a thermal insulation material having the following characteristics:

Thermal conductivity	0.08	(W/mK)
Specific heat	850.00	(J/kgK).
Specific mass of the material	200.00	(kg/m3).
Water content	0.00	(kg/m3).
Convection coefficient on hot surfaces.	25.00	
Convection coefficient on cold surfaces.	9.00	
Relative emissivity.	0.56	

Table 1:   Thermal properties of the protection

Boundary conditions

The imposed boundary conditions used in simulation were a heat flux of 100 kW/m2, on one half of the bar. Also a 20°C frontier on the entire length of the bar was imposed, for simulating the environment (see Figure 2) to which the structure re-radiates.
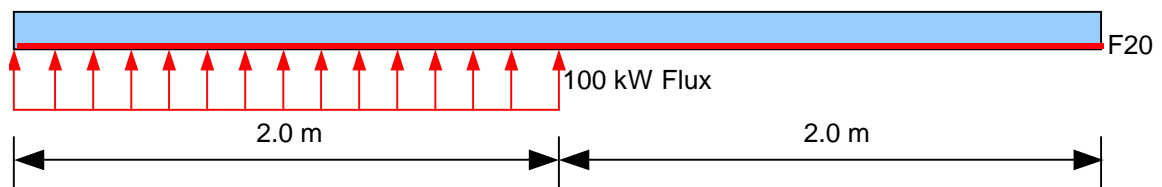
Figure 2: Boundary conditions.

In-depth results

Figure 3 shows the temperature distribution after 60 minutes in the protected bar with a 80 m-1 section factor, as presented by Diamond for SAFIR.

Below this, graphical representations of the obtained results are presented. For each case, the temperature evolution along the bar is given, followed by a zoom of the temperature evolution (between 1.2 m and 2.8 m).
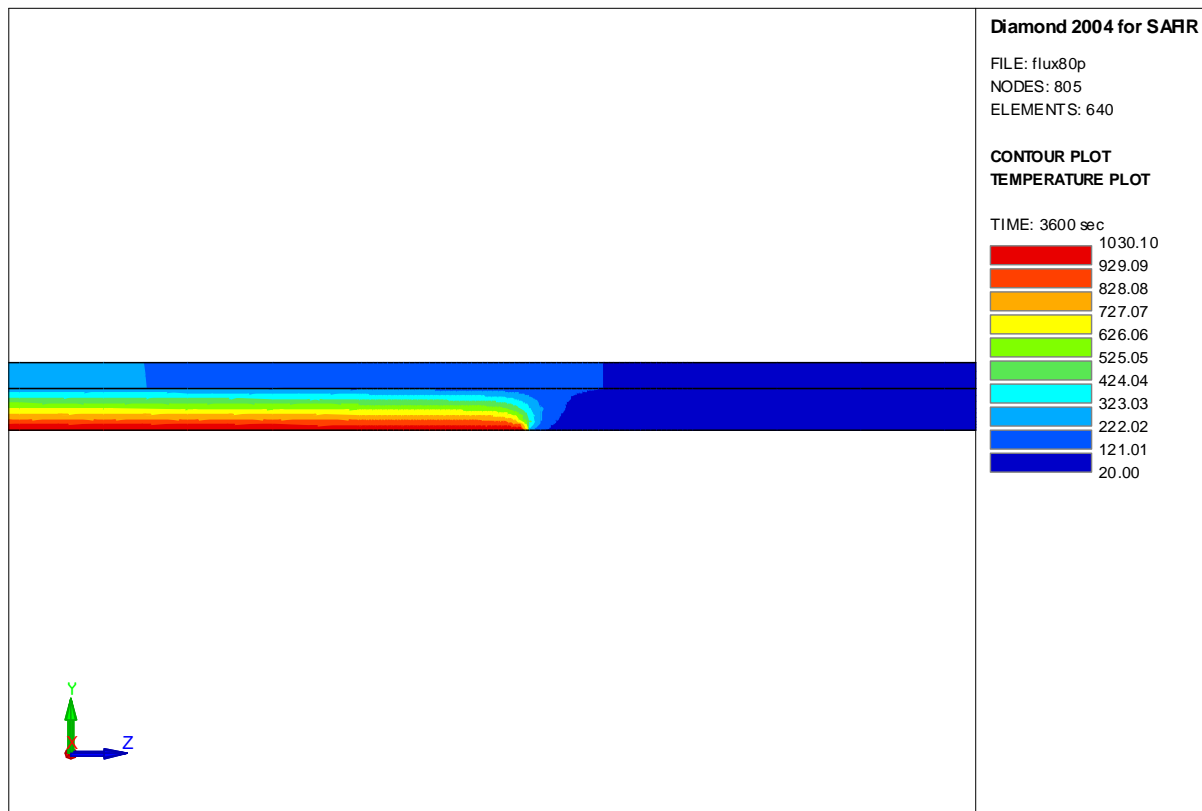
Figure 3: The temperature distribution after 60 minutes for the protected 80 m-1 steel bar.
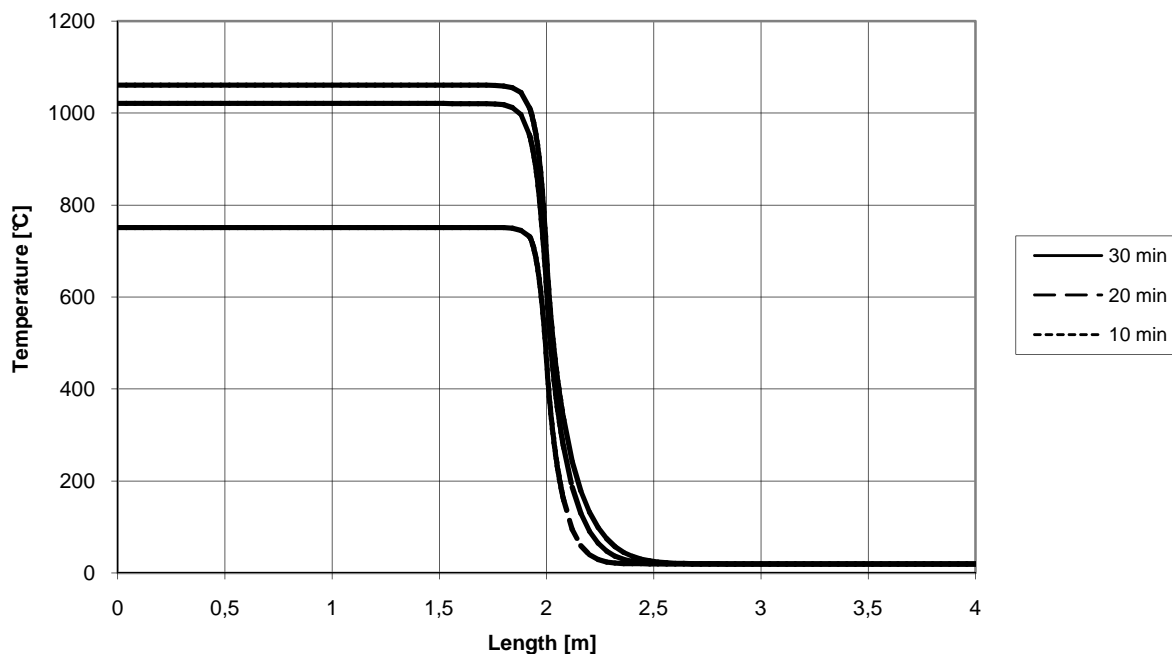
Figure 4: Unprotected bar, with 80 m-1 section factor.
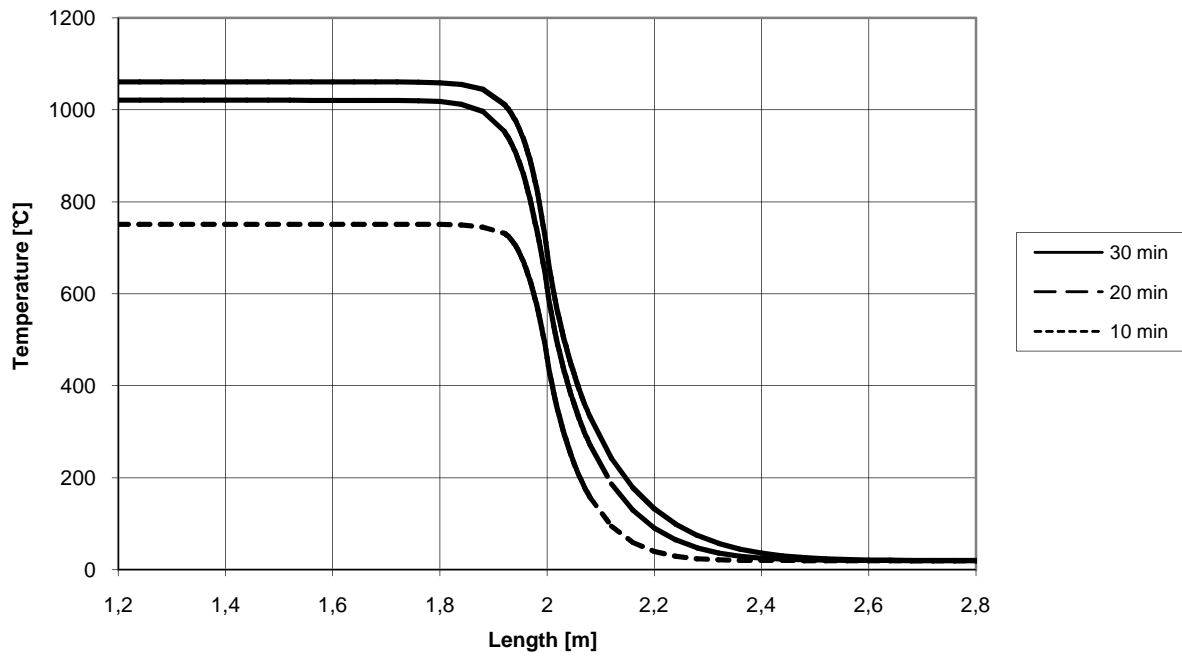
Figure 5: Unprotected bar, with 80 m-1 section factor (zoom).
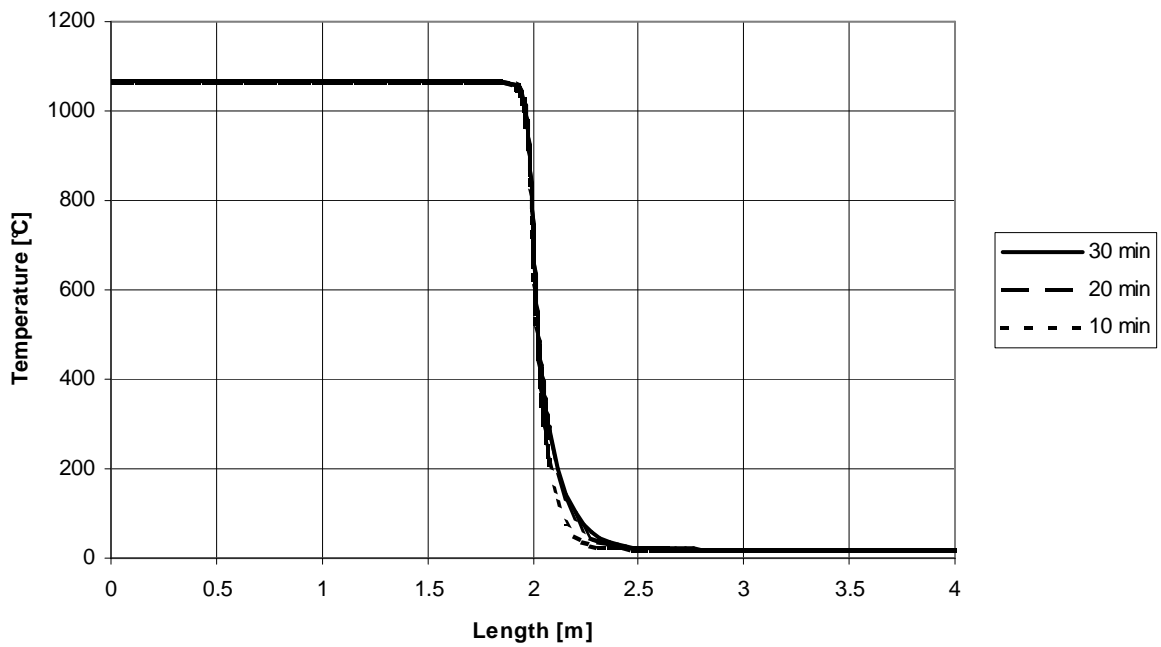
Figure 6: Unprotected bar, with 250 m-1 section factor.
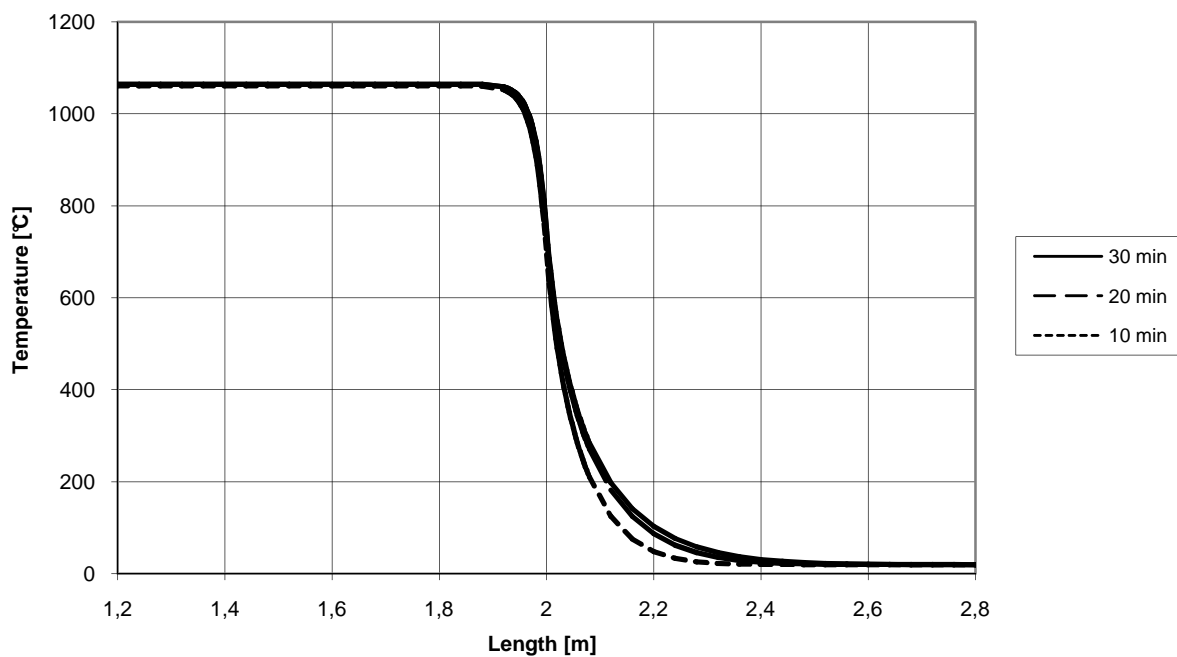
Figure 7: Unprotected bar, with 250 m-1 section factor (zoom).
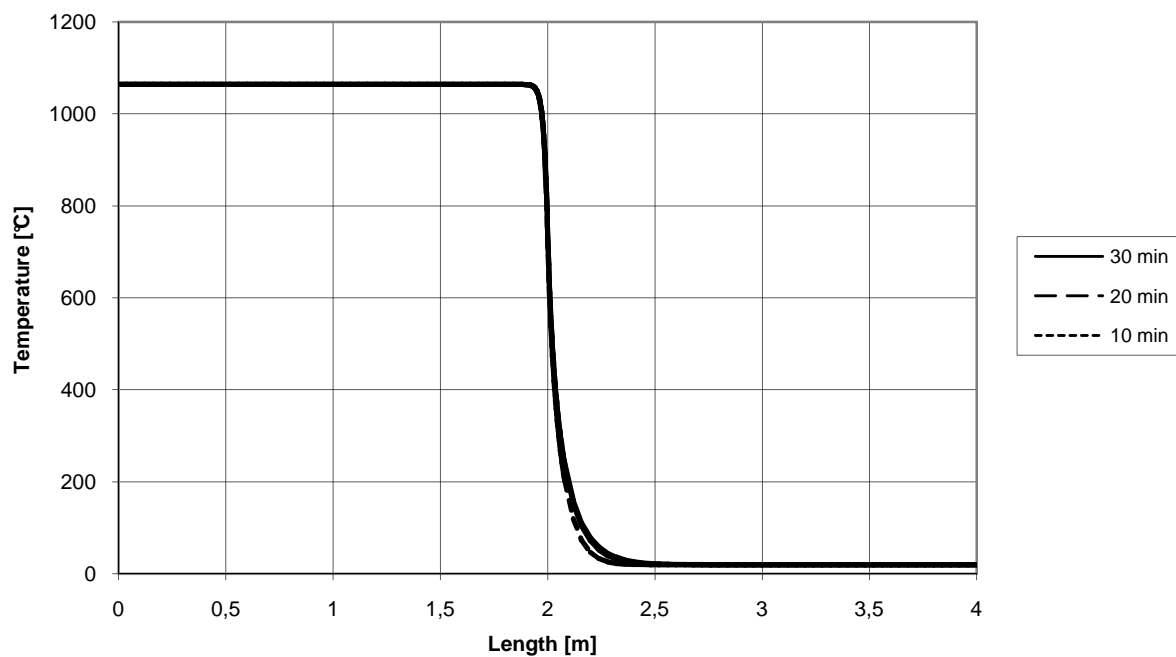
Figure 8:   Unprotected bar, with 400 m-1 section factor.
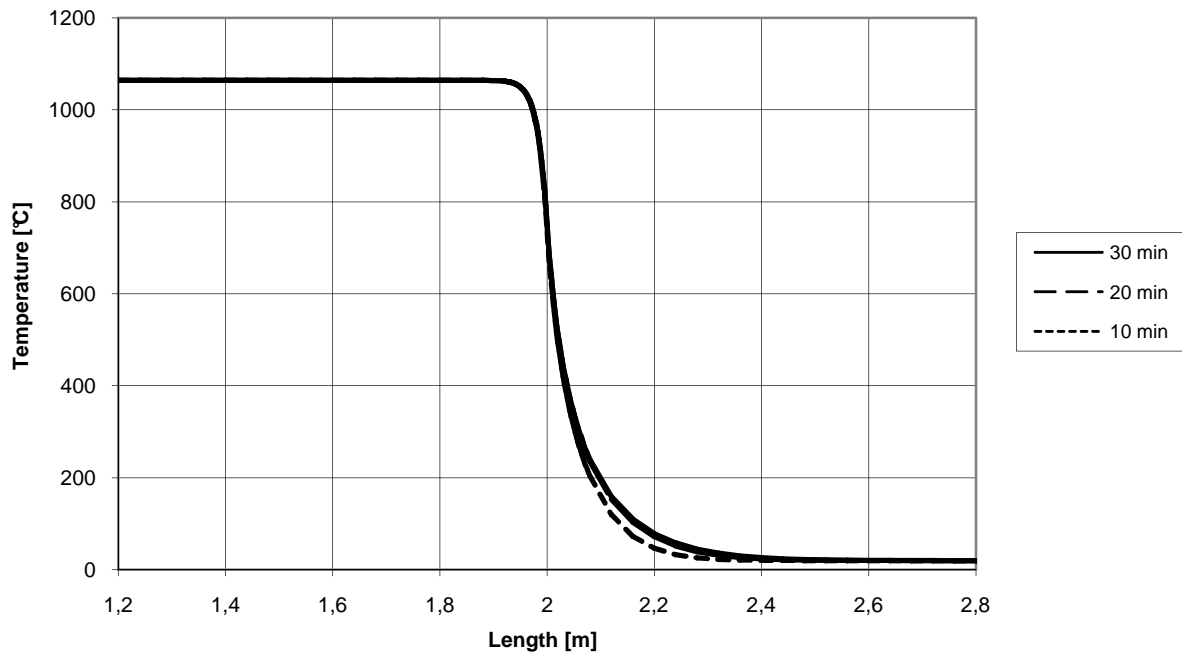
Figure 9: Unprotected bar, with 400 m-1 section factor (zoom).
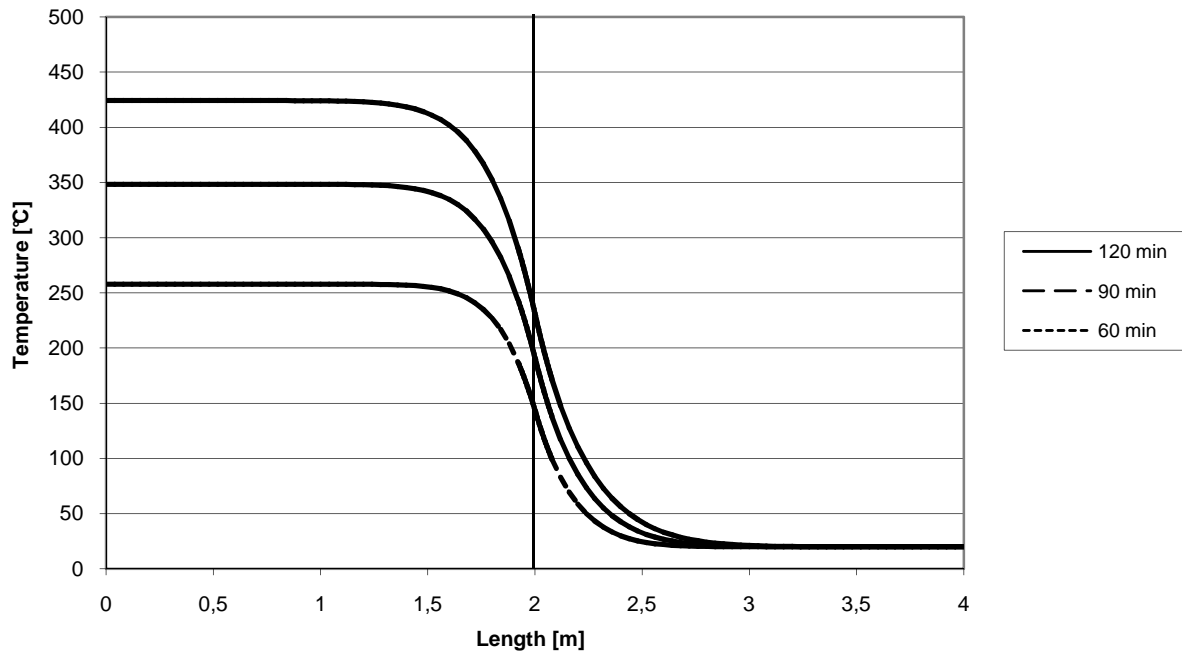
Figure 10:   Protected bar, with 80 m-1 section factor.
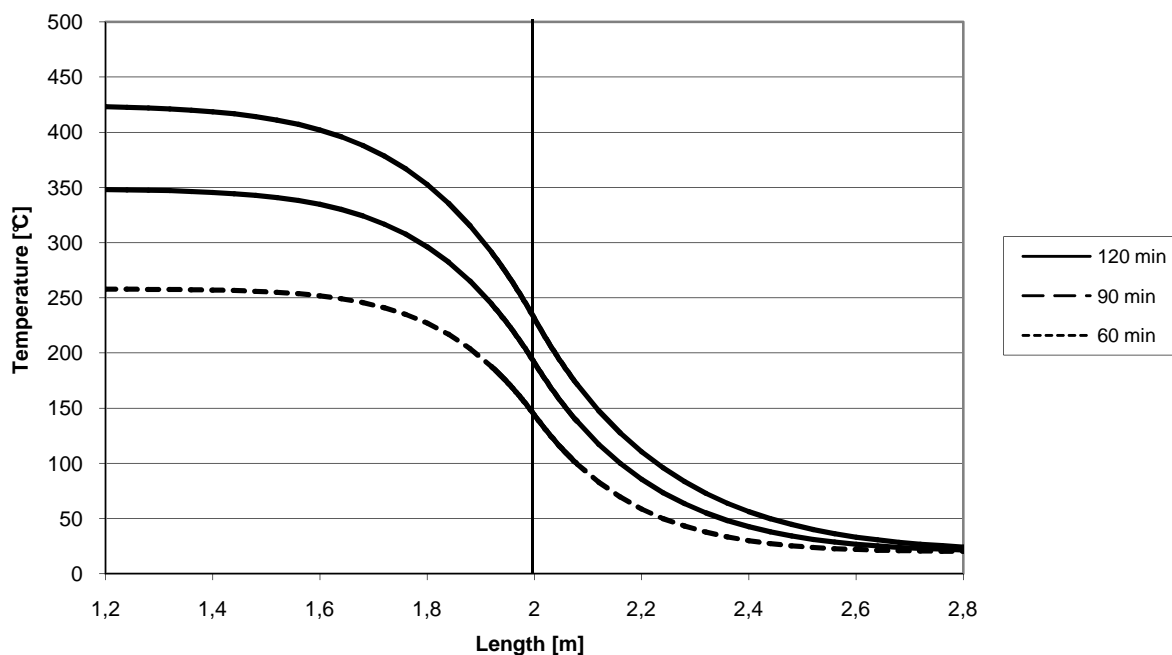
Figure 11:   Protected bar, with 80 m-1 section factor (zoom).
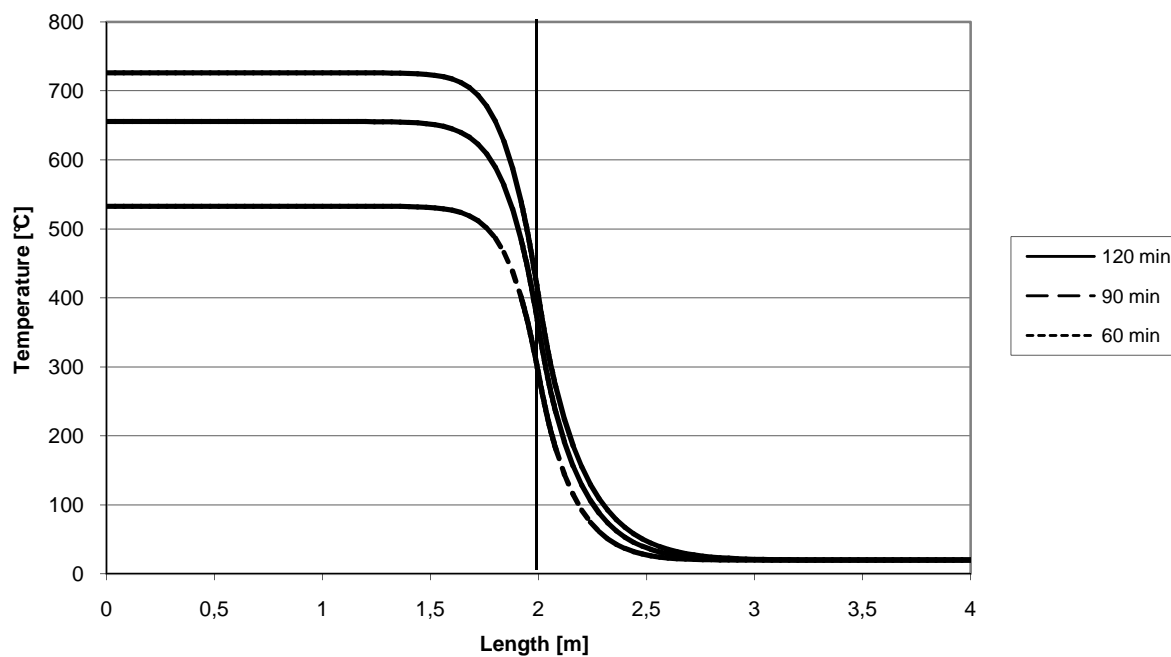
Figure 12:   Protected bar, with 250 m-1 section factor.
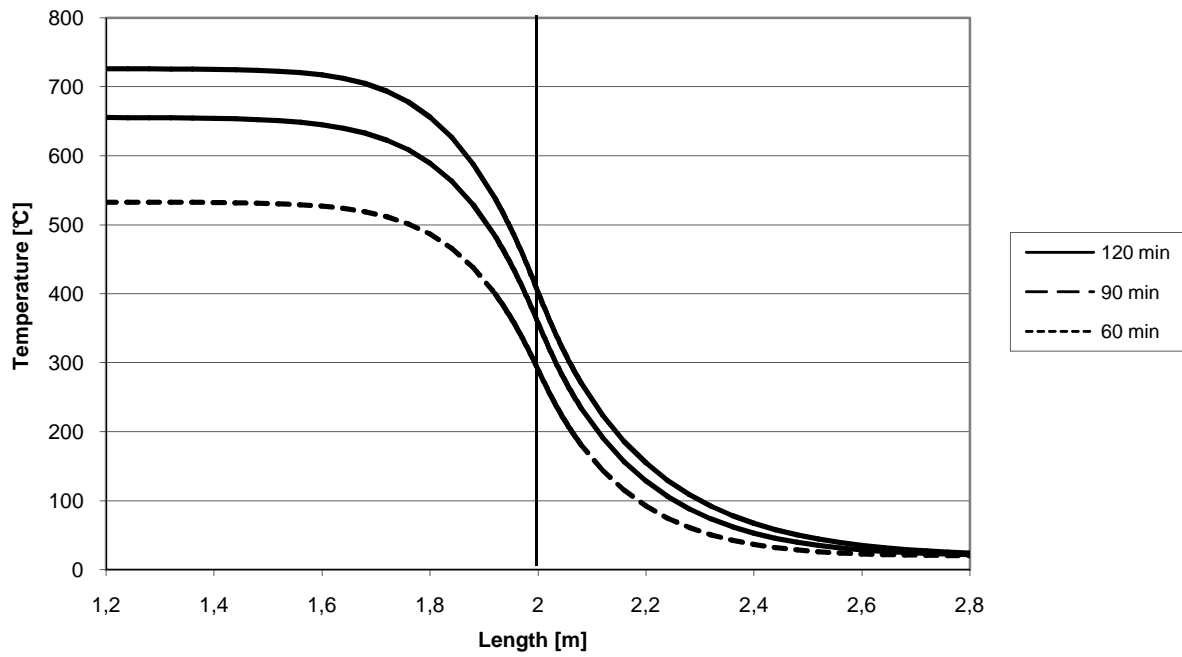
Figure 13:   Protected bar, with 250 m-1 section factor (zoom).
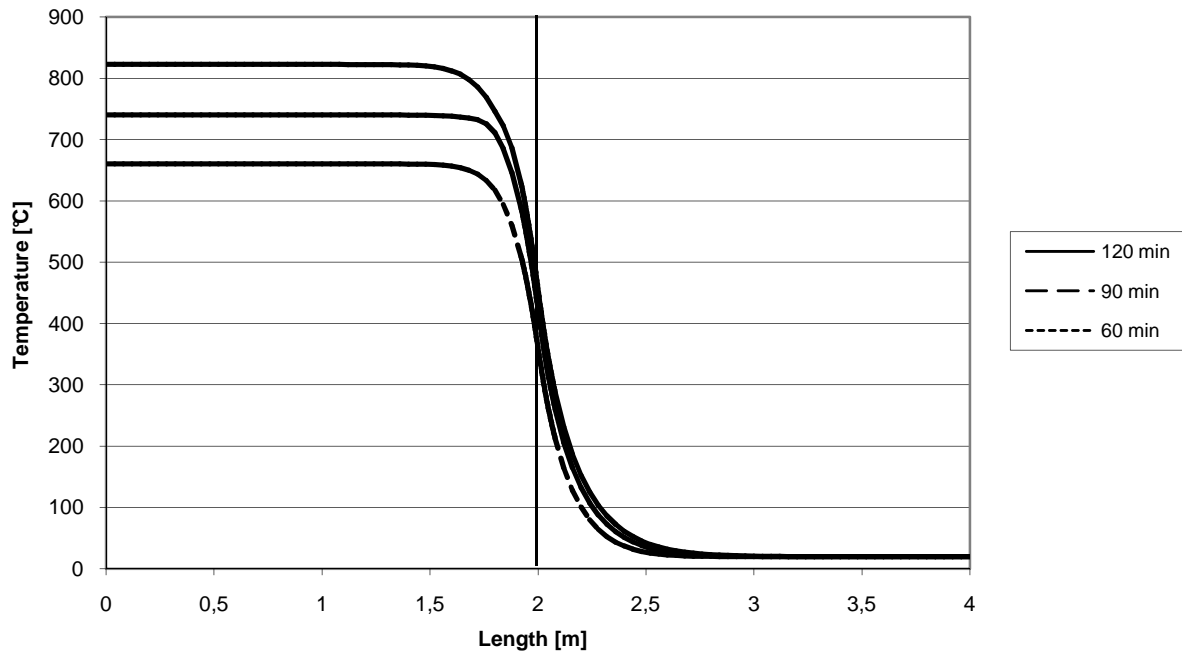
Figure 14:   Protected bar, with 400 m-1 section factor.
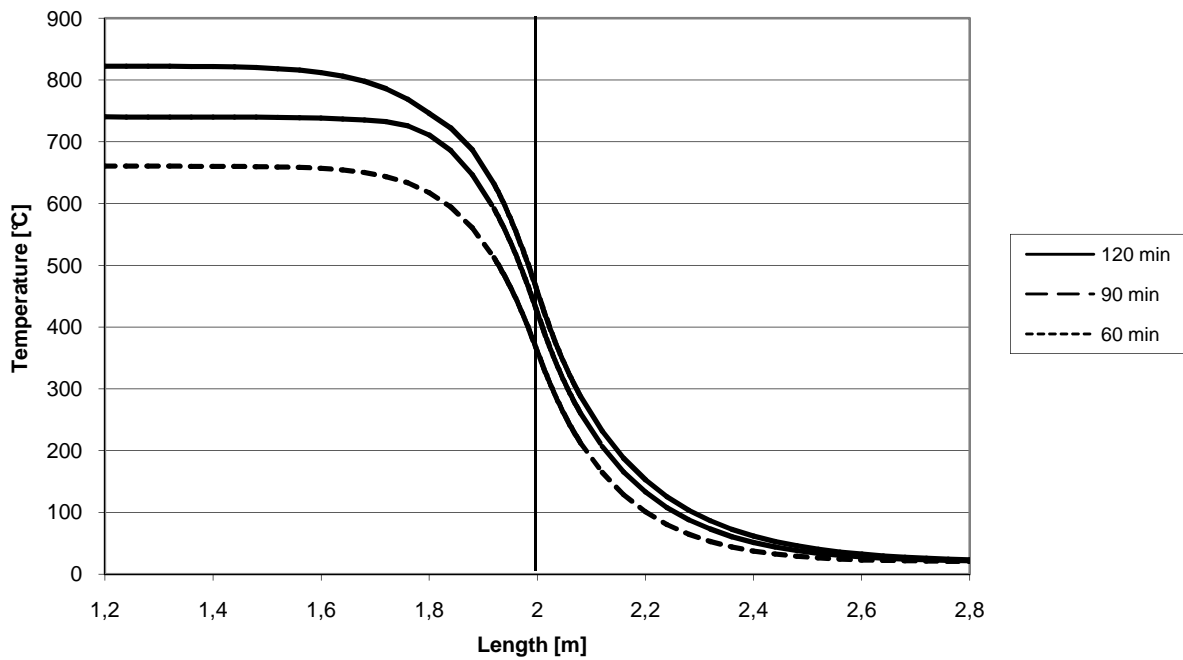
Figure 15:   Protected bar, with 400 m-1 section factor (zoom).

The table that follows gives the interface length. The length of the interface represents the distance from midpoint to the point along the bar where the temperature changes more than 5°C to the left (Hot zone) and to the right (Cold Zone) compared to the values at the end of the bar.

Section factor (m^{-1})	Protection	Time	Hot Zone	Cold Zone
80	Unprotected	10 min	12	24
80	Unprotected	20 min	16	40
80	Unprotected	30 min	16	48
250	Unprotected	10 min	8	28
250	Unprotected	20 min	8	40
250	Unprotected	30 min	8	44
400	Unprotected	10 min	6.8	28
400	Unprotected	20 min	6.5	36
400	Unprotected	30 min	6.5	40
80	Protected	60 min	40	48
80	Protected	90 min	52	64
80	Protected	120 min	60	76
250	Protected	60 min	40	52
250	Protected	90 min	44	68
250	Protected	120 min	44	76
400	Protected	60 min	36	52
400	Protected	90 min	28	64
400	Protected	120 min	44	72

Table 2:   Length of the interface [cm].

Conclusions

The fact that the temperature distribution does not vary at the end of the bars indicates that a sufficiently long distance has been modelled as to obtain on each side a situation that is not influenced by the other side, i.e. by the transition.

Even with this abrupt case of flux variation the length of the interface is not as severe as common sense tells us. Considering the point that gives the length of the interface as the one where a 5°C difference is noted compared to the temperature at the end of the bar, i.e. where there is no influence of the transition, the length on the hot side is only 10 cm for the unprotected steel or 45 cm for the protected steel. On the cold side the temperature drops on about 40 cm for the unprotected steel or 60 cm in the case of protected steel.

In a real case scenario where the variation of the flux is smoother than in our considered case the influence of the transition zone will be even smaller. Indeed, if a section submitted to a flux of 100 kW/m2 cannot "see" that the flux is equal to 0 at a distance of only 50 cm, it will be even less sensitive to the fact that the flux might be some kW/m2 lower in one direction and some kW/m2 higher in the other direction.

This leads to the fact that in a real case fire scenario a 3D temperature analysis can be replaced with a series of 2D analyses, the temperature distribution being sought in a series of sections, using an interpolation scheme to compute the temperatures along the bar.

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FIRE RESEARCH AT UNIVERSITAT POLITÈCNICA DE CATALUNYA - EPSEB

The Fire Laboratory of the Technical University of Catalonia, located at the School of Building Construction of Barcelona (EPSEB), conducts basic and applied research in problems related with fire propagation and the behavior of materials at high temperatures. On the one hand, the use of products which undergo endothermic decomposition for fire protection purposes is studied both theoretically and experimentally. On the other hand, studies of fire propagations based on CFD models are performed, in particular applied to the vertical propagation along the building façades and to the evolution inside railway vehicles.

Passive protection under fire

Substances undergoing endothermic reactions are of wide interest in the development of materials oriented to passive fire protection. Specifically, we have focused on obtaining mortars formulated with low-grade magnesium by-products, which undergo endothermic decompositions in a range between 300ºC and 800ºC. A detailed experimental work in order to characterize such a products and analyze their and viability was performed. From a theoretical point of view, the underlying non-isothermal kinetics of such reacting materials is not clearly understood, despite the large amount of research that has been devoted in this topic. Results for the heating rate dependence on the kinetic parameters, obtained with small-scale thermogravimetric techniques, have been incorporated into the modeling and numerical simulations of spatially extended systems.

References:

J.Formosa, L.Haurie, J.M.Chimenos, A.M. Lacasta, J.R.Rosell, "Comparative study of Magnesium by-products and vermiculite formulations to obtain fire resistant mortars", Materials Science Forum Vols. 587-588, pp 898-902 (2008).

J.Formosa, J.M.Chimenos, A.M.Lacasta, L.Haurie, J.R.Rosell, "New fire-proof mortars formulated with magnesium by-products", to appear in Cement and Concrete Research (2010).

A.Ciudad, A.M. Lacasta, L.Haurie, J.Formosa, J.M. Chimenos, "Theoretical and experimental analysis of the heat absorbing profile in passive fire protection materials", submitted to the International Journal of Heat and Mass Transfer, 2010.

Building-façade geometry and its impact on fire propagation

When there is a fire in a building, the façade can be one of the quickest spreading pathways. Among other countries, Spain has incorporated into its regulations measures to control vertical spreading along the façade. A critical study has been performed in order to evaluate whether these measures can be sufficient or not to build safer external walls. Several geometrical configurations, including protections in the form of both vertical elements (spandrels) and horizontal-projection elements, have been considered. A numerical study was conducted using FDS (Fire Dynamics Simulator), to analyze some aspects of the propagation path called "leap frog", which is the upward spread fire through window openings.

References:

M.P.Giraldo, J.Avellaneda, A.M.Lacasta, A.Ciudad, "Computer-simulation research on building-façade geometry and its impact on fire propagation", International Congress Combustion and Fire Dynamics, pp.493-506, ISBN 978-84-86116-23-1, Santander (Spain), 21-22 October 2010.

RAILCEN project: Evolution of fire in a railway vehicle

This project, funded by the Spanish Ministry of Science, is focused on the adaptation and classification of different materials to the new railway standard CEN/TS 45545-2. The research team is composed of four bodies : the Technical University of Catalonia (UPC), the Technological Center CIDEMCO-Tecnalia, and two leading companies in the railway field, Fainsa and Talgo. Extensive small-scale tests have been performed with the cone calorimeter, which is the technique used for classification according this new Standard. Complementary characterization techniques, like thermogravimetric analysis, differential scanning calorimetry, or thermal conductivity measurements, have been used in order to obtain other properties of the material necessary for the simulations with the Fire Dynamics Simulator (FDS). The final goal is to verify whether the small-scale characterization is adequate to reproduce the behaviour in larger fire scenarios. Simulation results have been compared with medium-scale tests on seat pairs in a specific cabin, and a large-scale test on a complete carriage is going to be performed.

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FIRE RESEARCH AT THE TECHNICAL UNIVERSITY OF OSTRAVA

Tools on risk assessment methods for fire safety engineering

The situation in field of fire safety and building industry heads toward development of standards, which alter safety level better than conventional norms aimed at solving individual problems. These changes are motivated by the need of more flexible ways of building designing and by the necessity to facilitate less expensive solutions, especially in the case of large structures, without reducing the safety level. From this originates the space for elaborating the different method of fire safety, which accuracy depends not only on chosen calculation method but also on technical opinion based on experiences and logical thinking of designer using all available information. For instance in the Czech Republic there is for this the recommended content of different procedure for fulfilment of fire safety technical conditions within project standards ČSN 73 0802 and ČSN 73 0804.

During fire safety engineering assessing tools on risk assessment methods for fire safety engineering bring to the designer necessary design parameters to subsequently consider fire risks and determine strategy system for maintenance of acceptable risk. During identification of the fire risk and its possible consequences could be helpful also available statistic data, which nevertheless determine just framework in which it is possible to move around. In the factual objects and situations it must be decided according to experiences or on the basis of collective dealing with other experts.

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Verification of fire safety in road tunnels

Even though the probability of fire, or other extraordinary incident, in the tunnels is usually lower than in other structures, these situations are attended by often tragic consequences regarding the number of injured and casualties. Also property damages and frequently long-term consequential actions after the incident cause considerable financial losses.

At present, minimum safety requirements for the operation of road tunnels are determined by regulations of European Union with a view to achieve the standardization of the requirements for ensuring the safety of especially long tunnels. A result is to be the attainment of a uniform, permanent and high level of safety of all citizens of Europe using road tunnels in the Trans-European Road Network. To this goal, harmonized requirements of individual countries of European Community must be subordinated. Ones of the basic European regulations concerning the safety requirements for tunnels are the White Paper – European Transport Policy for 2010 – time to decide, and Directive 2004/54/EC of the European Parliament and of the Council on minimum safety requirements for tunnels in the Trans-European Road Network. On the mentioned documents, regulations of individual European countries are based on keeping at least the same minimum level of safety.

In addition the tunnel structures are equipped with a number of technical devices, which serve to ensure their safety (e.g. traffic system, control system, electrical power supply, ventilation system). It is obvious that equipment of the tunnels with safety devices and its correct operation in the case of an extraordinary incident implicates largely the effective intervention of rescue units. The importance of installed technical

devices with safety function leads among others to the requirement on rigorous verifications of their efficiency before putting tunnels into operation.

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Appendix

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OVERVIEW OF THE PRINCIPLES OF HEAT TRANSFER

The transfer of heat is normally from a high temperature object to a lower temperature object. Heat transfer changes the internal energy of both systems involved according to the First Law of Thermodynamics.

The Heat Transfer can be done by:

- Conduction

- Convection

- Radiation

- Vaporization

- Some definitions

Heat

Heat may be defined as energy in transit from a high temperature object to a lower temperature object. An object does not possess "heat"; the appropriate term for the microscopic energy in an object is internal energy. The internal energy may be increased by transferring energy to the object from a higher temperature (hotter) object - this is properly called heating.

Is related to changes in internal energy through	Q Heat	Causes temperature changes affected by
First Law of Thermodynamics $\Delta U = Q - W$		Specific Heat $Q = c \cdot m \cdot \Delta T$

In mechanisms for

Heat Transfer

$$\frac{Q}{t} = k \cdot A \cdot \frac{\Delta T}{d}$$
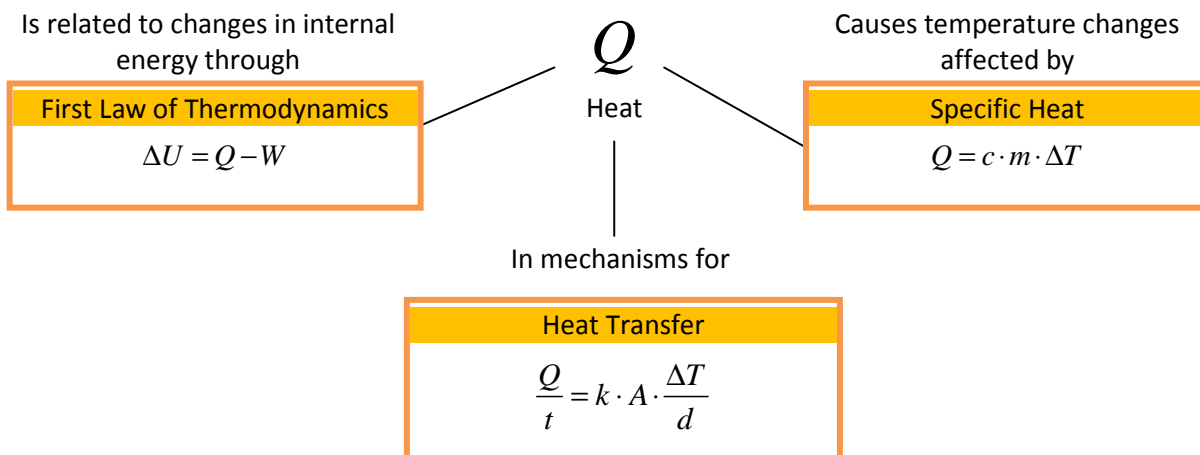
Specific Heat

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius. The relationship between heat and temperature change is usually expressed in the form shown below where c is the specific heat. The relationship does not apply if a phase change is encountered, because the heat added or removed during a phase change does not change the temperature.

$$Q = c \cdot m \cdot \Delta T$$

where:

Q = the heat added

c = the specific heat

m = the mass

ΔT = the change in temperature

The specific heat of water is 1 calorie/gram °C = 4.186 joule/gram °C which is higher than any other common substance. As a result, water plays a very important role in temperature regulation. The specific heat per gram for water is much higher than that for a metal, as described in the water-metal example. For most purposes, it is more meaningful to compare the molar specific heats of substances.

The molar specific heats of most solids at room temperature and above are nearly constant, in agreement with the Law of Dulong and Petit. At lower temperatures the specific heats drop as quantum processes become significant. The low temperature behavior is described by the Einstein-Debye model of specific heat.

Temperature

A convenient operational definition of temperature is that it is a measure of the average translational kinetic energy associated with the disordered microscopic motion of atoms and molecules. The flow of heat is from a high temperature region toward a lower temperature region. The details of the relationship to molecular motion are described in kinetic theory. The temperature defined from kinetic theory is called the kinetic temperature. Temperature is not directly proportional to internal energy since temperature measures only the kinetic energy part of the internal energy, so two objects with the same temperature do not in general have the same internal energy. Temperatures are measured in one of the three standard temperature scales (Celsius, Kelvin, and Fahrenheit).
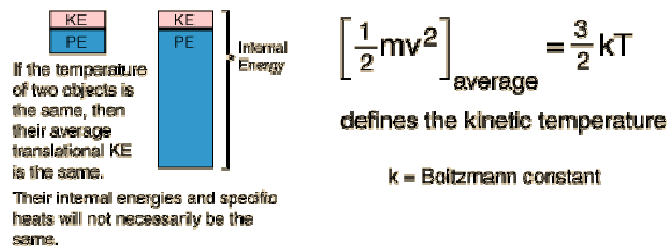
Internal Energy

Internal energy is defined as the energy associated with the random, disordered motion of molecules. It is separated in scale from the macroscopic ordered energy associated with moving objects; it refers to the invisible microscopic energy on the atomic and molecular scale. For example, a room temperature glass of water sitting on a table has no apparent energy, either potential or kinetic. But on the microscopic scale it is a seething mass of high speed molecules traveling at hundreds of meters per second. If the water were tossed across the room, this microscopic energy would not necessarily be changed when we superimpose an ordered large scale motion on the water as a whole.

U is the most common symbol used for internal energy. Related energy quantities which are particularly useful in chemical thermodynamics are enthalpy, Helmholtz free energy, and Gibbs free energy.

First Law of Thermodynamics

The first law of thermodynamics is the application of the conservation of energy principle to heat and thermodynamic processes.

The change in internal energy of a system is equal to the heat added to the system minus the work done by the system:

$$\Delta U = Q - W$$

Where:

ΔU = the change in internal energy

Q = the heat added to the system
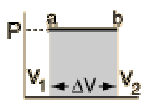
W = the work done by the system

The first law makes use of the key concepts of internal energy, heat, and system work. It is used extensively in the discussion of heat engines.

It is typical for chemistry texts to write the first law as $\Delta U = Q + W$. It is the same law, of course - the thermodynamic expression of the conservation of energy principle. It is just that W is defined as the work done on the system instead of work done by the system. In the context of physics, the common scenario is one of adding heat to a volume of gas and using the expansion of that gas to do work, as in the pushing down of a piston in an internal combustion engine. In the context of chemical reactions and process, it may be more common to deal with situations where work is done on the system rather than by it.

System Work

When work is done by a thermodynamic system, it is usually a gas that is doing the work. The work done by a gas at constant pressure is:

$$W = P \cdot \Delta V$$

The line from a to b represents an expansion of a gas at constant pressure. The work done is the area under the curve.

For non-constant pressure, the work can be visualized as the area under the pressure-volume curve which represents the process taking place. The more general expression for work done is:

The integral expression gives the exact area under the curve which is equal to the work.

$$W = \int_{V_1}^{V_2} P dV$$

Work done by a system decreases the internal energy of the system, as indicated in the First Law of Thermodynamics. System work is a major focus in the discussion of heat engines.

Heat Conduction

Conduction is heat transfer by means of molecular agitation within a material without any motion of the material as a whole. If one end of a metal rod is at a higher temperature, then energy will be transferred down the rod toward the colder end because the higher speed particles will collide with the slower ones with a net transfer of energy to the slower ones. For heat transfer between two plane surfaces, such as heat loss through the wall of a house, the rate of conduction heat transfer is:
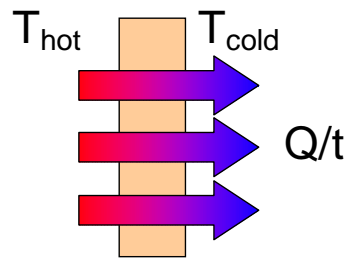
$$\frac{Q}{t} = \frac{\kappa A \left(T_{hot} - T_{cold} \right)}{d}$$

Where

Q = heat transferred in time t

κ = thermal conductivity of the barrier

A = area

T = temperature

d = thickness of barrier

Heat Convection

Convection is heat transfer by mass motion of a fluid such as air or water when the heated fluid is caused to move away from the source of heat, carrying energy with it. Convection above a hot surface occurs because hot air expands, becomes less dense, and rises (see Ideal Gas Law). Hot water is likewise less dense than cold water and rises, causing convection currents which transport energy.
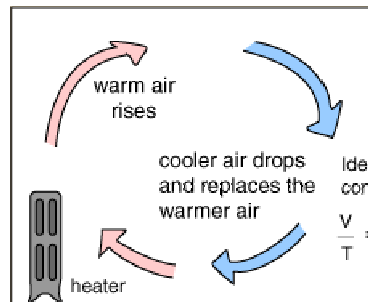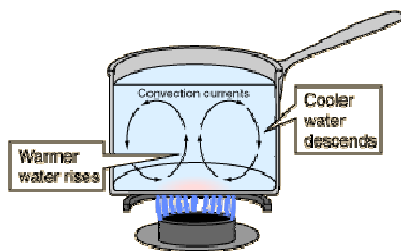
Convection can also lead to circulation in a liquid, as in the heating of a pot of water over a flame. Heated water expands and becomes more buoyant. Cooler, more dense water near the surface descends and patterns of circulation can be formed, though they will not be as regular as suggested in the drawing.

Heat Radiation

Radiation is heat transfer by the emission of electromagnetic waves which carry energy away from the emitting object. For ordinary temperatures (less than red hot"), the radiation is in the infrared region of the electromagnetic spectrum. The relationship governing radiation from hot objects is called the Stefan-Boltzmann law:

$$P = e \cdot \sigma \cdot A\left(T^4 - T_c^4\right)$$

P = net radiated power

e = emissivity (= 1 for ideal radiator)

A = radiating area

T = temperature of the radiator

T_c = temperature of the surrounding

σ = Stefan Boltzmann constant = 5.6703·10-8 W/m2K4

Heat Transfer by Vaporization

If part of a liquid evaporates, it cools the liquid remaining behind because it must extract the necessary heat of vaporization from that liquid in order to make the phase change to the gaseous state. It is therefore an important means of heat transfer in certain circumstances, such as the cooling of the human body when it is subjected to ambient temperatures above the normal body temperature.

Heat of Vaporization
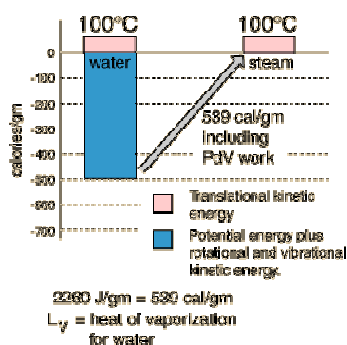
The energy required to change a gram of a liquid into the gaseous state at the boiling point is called the "heat of vaporization". This energy breaks down the intermolecular attractive forces, and also must provide the energy necessary to expand the gas (the P⬚V work). For an ideal gas , there is no longer any potential energy associated with intermolecular forces. So the internal energy is entirely in the molecular kinetic energy.

The final energy is depicted here as being in translational kinetic energy, which is not strictly true. There is also some vibrational and rotational energy.

A significant feature of the vaporization phase change of water is the large change in volume that accompanies it. A mole of water is 18 grams, and at STP (state variable entropy, temperature, pressure) that mole would occupy 22.4 liters if vaporized into a gas. If the change is from water to steam at 100°C, rather than 0°C, then by the ideal gas law that volume is increased by the ratio of the absolute temperatures, 373K/273K, to 30.6 liters. Comparing that to the volume of the liquid water, the volume expands by a factor of 30600/18 = 1700 when vaporized into steam at 100°C. This is a physical fact that firefighters know, because the 1700-fold increase in volume when water is sprayed on a fire or hot surface can be explosive and dangerous.

One way to visualize this large volume change is to note the volume of 18 ml of water in a graduated cylinder as the volume occupied by Avogadro's number of water molecules in the liquid state. If converted into steam at 100°C this same mole of water molecules would fill a balloon 38.8 cm in diameter (15.3 inches).

WG2

Structural Safety in Fire

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GLOBAL MODELLING OF FIRE-AFFECTED STRUCTURES

Understanding the global behaviour of all but simplest of structures in fire has only been possible since the development of suitable numerical tools and modelling techniques. Considerable research effort has been dedicated in recent years to providing the knowledge needed for this and much progress has been made. It turns out that structural behaviour in fire in all but the simplest cases is much more complex than analyses based solely on loss of material strength due to heating, such as those based on the Standard Fire Test, can predict. A key aspect of the findings of recent research is that analyzing structural elements, such as beams and columns, in isolation and with idealized supports (as is common at ambient temperature) in a fire analysis is insufficient if an understanding of the fire resistance of entire structures is desired. For accurate results to be produced, either the behaviour of whole structures or the behaviour of large parts of structures with appropriate boundary conditions must be considered. As a result in all but the most straightforward cases numerical analyses are required to accurately predict the strength and behaviour of structures in fire.

Modelling the Cardington Tests

Much of the early development of numerical modelling of heated structures was validated against the fire tests undertaken on the Cardington Frame, a full-scale steel-concrete composite structure on which fire tests were undertaken. The Cardington frame is one of the very few full-scale structures that have ever been tested in fire while heavily instrumented. Consequently, it allowed real and numerically predicted responses to be readily compared. Full data including deflections, strains, rotations and temperatures during a sequence of four fire tests is freely available and numerous numerical models have been developed to represent these tests. The Cardington tests have been widely used as a benchmark when developing numerical models for both stress and heat transfer analyses.

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M. Gillie, A.S. Usmani, J.M. Rotter. A structural analysis of the first Cardington test. Journal of Constructional Steel Research 57(6) 581-601, 2001.

Modelling the Collapse of Fire-affected Structures

The collapse behaviour of fire-affected structures has recieved close attention since the World Trade Center attacks. Modelling approaches have been developed and various collapse mechanisms identified for the high-rise structures subject multi-floor fires. Research has examined both how a structure responds

to such fires and also how the fires themselves may develop. Optimal numerical schemes for modelling structural collaspe have also been identified.

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Rein G el at (2007c), "Multi-story Fire Analysis for High-Rise Buildings", Proceedings of the 11th International Interflam Conference, London, Sept. 2007. http://hdl.handle.net/1842/1980

G Flint, AS Usmani, S Lamont, J Torero and B Lane, Effect of fire on composite long span truss floor systems, Journal of Constructional Steel Research, 62(4) 303-315, 2005

Development of Material Models

Numerically representations of material behaviour, particularly concrete, at high temperature have developed rapidly recently. It has become possible to include and increasingly comprehensive range of material phenomena in numerical models such as plasticity, transient thermal strains, strain softening, cracking and crushing.

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A Law. The Assessment and Response of Concrete Structures Subject to Fire PhD Thesis, University of Edinburgh 2010.

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FULLY COUPLED TEMPERATURE-DISPLACEMENT ANALYSES OF STEEL STRUCTURES UNDER FIRE

Motivation

The behaviour of steel structures under fire needs particular attention since the structural steel undergoes considerable deterioration in presence of high temperatures, such as the reduction of both resistance and stiffness of steel. This can cause the collapse of structures that are safely designed for ordinary load combinations, in which the fire scenario is disregarded. Consequently, the behaviour in fire of steel structures requires deep investigations from both experimental and numerical points of view.

Methodology

On the basis of such considerations, many efforts have been made in recent years in order to evaluate the performances of steel structures under fire. Recently a numerical study aimed at investigating the behaviour of steel structures under fire based on the use of fully coupled temperature-displacement finite element analyses, carried out by means of the advanced computer program ABAQUS has been presented. The used method allows to consider at the same time the mechanical and thermal aspects of the problem. The mechanical and thermal problems are faced up in a unique model, in which the actual phases of the modeled phenomenon, say the sequential application to the structure of the design loads and, then, of the fire scenario, are reproduced in a step-by-step analysis. Such approach differs from the usually adopted one, which consists, for the sake of simplicity, in performing the heat transfer analysis and the mechanical one separately (uncoupled analyses): the first one allows to evaluate the temperature-time law within the structural elements exposed to fire, completely neglecting the stress-displacement aspect; the second one consists in the usual structural analysis, in which the structure is subjected to the external loads; at the end of the structural analysis, the temperature-time variation, obtained from the preliminary heat transfer analysis, is imposed to the structural members, so allowing the calculation of the fire resistance of the structure. On the contrary, in the case of fully coupled temperature-displacement analyses, the used finite elements are endowed with both displacement and temperature degrees of freedom, so that the mechanical and thermal equations are written simultaneously and the mutual interactions between the two aspects of the problem can be easily caught.

Application

Applications have been carried out to simple steel portal frames, focusing on the main geometrical and mechanical parameters that influence the fire resistance of the considered structures, such as the span over height ratio, the massivity ratio of the structural members, the steel grade and the exploitation degree of the material. However such a methodology was already applied for the investigation of the behaviour of steel structures exposed to fire after being damaged by an earthquake.
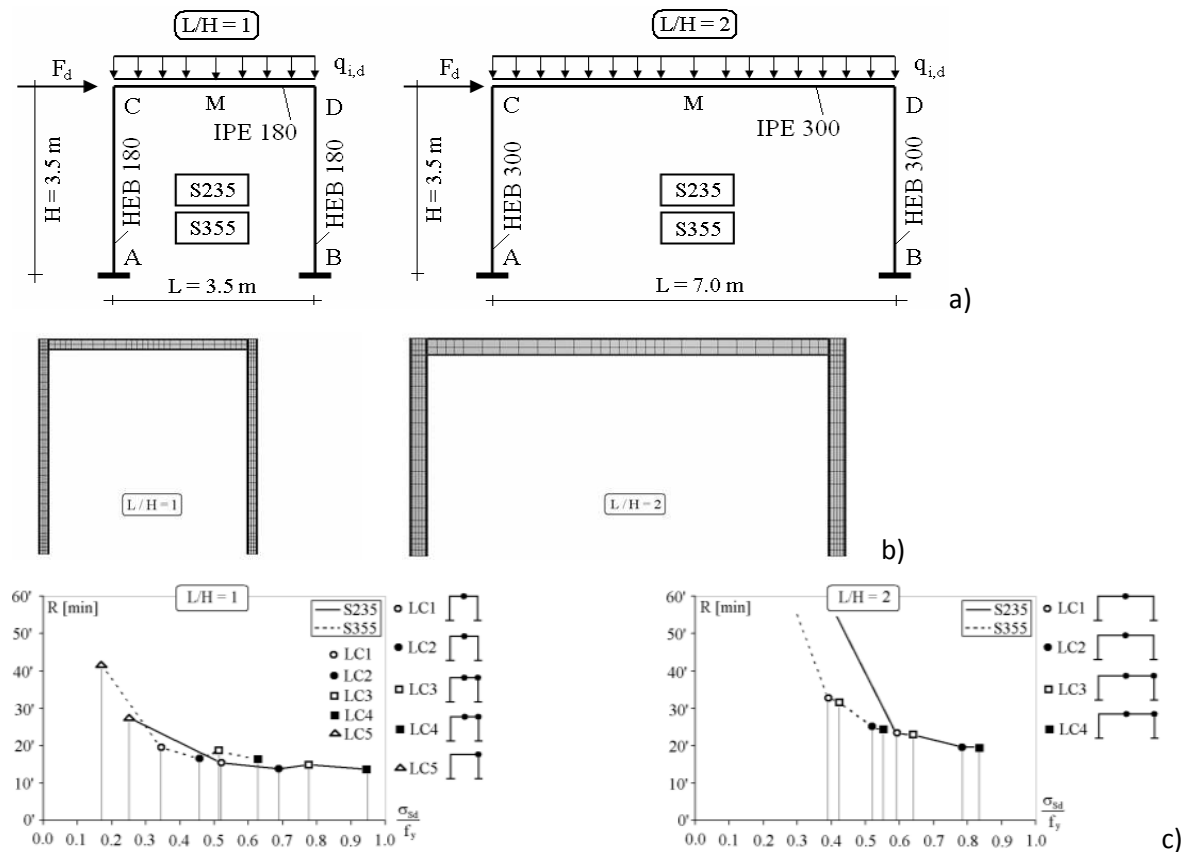
Figure 1. a) case studies; b) finite element meshes of the models; c) results.

Further developments

Further studies are needed and will be carried out, in order to enlarge the comprehension of the study phenomenon and to establish the efficiency of the refined model. Additional analyses, based on the same adopted methodology, will increase the number of the considered mechanical and geometrical parameters. Moreover, the analyses will be extended to multi-span multi-storey frames, with the possibility of studying the effects of the fire position in the frames.

References:

Faggiano B., Esposto M., Mazzolani F.M. 2007. Fully coupled temperature – displacement analyses of steel portal frames under fire. Proceedings of the National Conference XXI Congresso CTA, Costruire con l'acciaio, Catania, Italia, a cura di A. Ghersi, Flaccovio Editore, ISBN 978-88-7758-787-9, pp. 561-568.

Faggiano B., Esposto M., Mazzolani F.M., Landolfo R. 2007. Fire analysis on steel portal frames damaged after earthquake according to performance-based design. Proceedings of the Workshop in Prague Urban Habitat Constructions under catastrophic events, COST-Action C26, Prague, Czech Republic, March 2007, F. Wald et al. (Eds.), Print Prazska technica, ISBN: 978-80-01-03583-2, pp. 35-40.

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METHODOLOGY FOR THE ROBUSTNESS ASSESSMENT OF STRUCTURES SUBJECTED TO FIRE FOLLOWING EARTHQUAKE THROUGH A PERFORMANCE-BASED APPROACH.

Motivation

In order to preliminary take into account in the design phases the effect of the combination of the seism and fire accidental loads, a methodology aimed at the robustness assessment under fire of structures already damaged to different extent by the earthquake, through a performance- based approach, is envisaged. The procedure should be valuable as a design tool in all seismic prone area, as it is suitable for buildings of high strategic importance.

Methodology

A methodology for the assessment of the robustness of structures subjected to fire following earthquake should apply a performance-based approach inspired from the FEMA 356 Guidelines and the philosophy of the Fire Safety Engineering, it considering each behavioural condition to be undergone by the construction, from the application of vertical service loads, through the earthquake-induced damage, up to the exposure of the structure to fire (Faggiano et al. 2010).

The methodology consists of two main subsequent phases:

1) the identification of the seismic damage state, according to the pre-fixed seismic performance levels, in relation to the intensity of the seismic event;

2) the determination of the residual bearing capabilities of the seismic damaged structures subjected to fire, according to pre-fixed fire performance levels, in relation to the fire event.

The preliminary task to be accomplished is the definition of the fire performance levels. They could be easily borrowed in the general terms from the seismic ones (FEMA 356), as it follows:

Operational fire (Of): Very Light overall damage; it shall be defined as the fire damage state in which the structural and non-structural components are able to support the pre-event functions present in the building.

Immediate Occupancy fire (IOf): Light overall damage; it shall be defined as the fire damage state that preserves equipments and contents and guarantees the structure to remain safe to be occupied.

Life Safety fire (LSf): Moderate overall damage; it shall be defined as the fire damage state that guarantees the structure to retain a safety margin against onset of partial or total collapse, while architectural, mechanical and electrical systems are damaged.

Collapse Prevention fire (CPf): Severe overall damage; it shall be defined as the fire damage state that allows the structure to support gravity loads, without retaining a safety margin against collapse; while extensive damage to the non structural components are present.

Application

The procedure is illustrated with reference to a simple steel framed structure made of S275 steel, whose geometrical features are shown in Figure 2. Equivalent static incremental seismic analyses and fire analyses have been carried out by means of the ABAQUS Ver.6.5 software (2004).

The seismic performance levels for a steel structure can be characterized by the extent of the inter-storey drift δ/h (where δ is the lateral displacement and *h* is the storey height) and the plastic hinge rotation Θ according to the FEMA 356 Guidelines. The reference values indicated in Figure 2c have been assumed. For the sake of brevity and simplicity, as a first rough attempt of application, the performance levels in fire have been identified with reference only to structural damage, according to definitions that are strictly pertinent to steel structures (Figure 2c).

The results, in terms of the time (s) necessary to reach the different performance fire levels, starting from the predetermined seismic performance levels IO, LS, CP1 and CP2 are indicated in Figure 2d, with reference to the condition of fire on half structure only.

Seismic performance level

PERFORMANCE LEVEL		δ/h [%]	Θ [rad]
Immediate Occupancy	(IO)	0.7	-
Life Safety	(LS)	2.5	-
Collapse Prevention 1	(CP1)	5.0	-
Collapse Prevention 2	(CP2)	-	0.05

Fire performance level
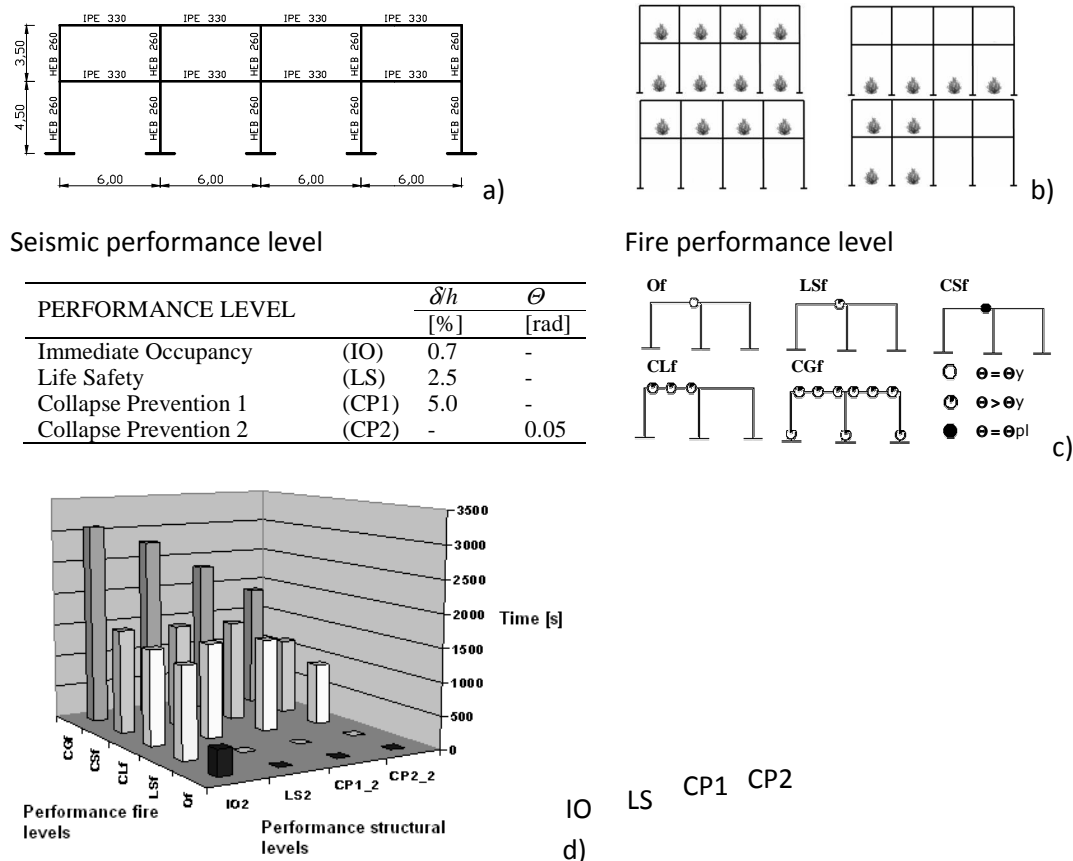
Figure 2: a) Case study; b) Fire location; c) Performance levels; d) Results (Faggiano et al. 2010).

Further developments

The fire after earthquake performance chart seems to be a very useful and powerful tool both for fire after earthquake capability analysis and for fire after earthquake design. In fact for a given structural type, given a fire scenario, once fixed the seismic damage extent corresponding to the design seismic performance level, it is possible either to carry out a fire performance capability analysis according to the prefixed fire performance level, or to design the structure in fire in order that it could reach the fire performance level required at the given acceptable time.

This methodology is particularly appropriate for the analyses of constructions of particular strategic or historic- monumental importance. In the first case (hospitals, police station, government buildings), it is necessary to guarantee performance levels able to assure the usability of all functions of the buildings also under effect of a fire after seism. In the second case (churches, museum, villas, palace, theatres), the safety

measures must be balanced with conservation requirements of the historic-artistic heritage. So for both cases, the standard seismic or fire regulations cannot be applied.

In this perspective, for the future, the development of this study must be directed to individuate and quantify the fire performance levels peculiar of the particular classes of buildings.

References:

Faggiano B., de Gregorio D., Mazzolani F.M., 2010. Assessment of the robustness of structures subjected to fire following earthquake through a Performance-Based approach. Proceedings of the International Conference COST Action C26 Urban habitat constructions under catastrophic events, Naples, Italy, 16-18 September 2010. ISBN 978-0-415-60685-1. pp: 207-212.

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FIRE SAFETY ENGINEERING FOR BUILDINGS AND OPEN CAR PARKS.

Research significance

According to ISO/TR 13387-1, the Fire Safety Engineering (FSE) is the application of engineering principles, rules and expert judgement based on a scientific appreciation of the fire phenomena, the effects of fire and the reaction and behaviour of people, in order to: save life, protect property and preserve the environment and heritage; quantify the hazards and risk of fire and its effects; evaluate analytically the optimum protective and prevention measures necessary to limit, within prescribed levels, the consequences of fire.

The performance-based approach, as opposed to prescriptive one, is based on a detailed analysis of the structural behaviour using advanced analytical models. Therefore, through the engineering method, following the steps in the layout of Figure 1, it is possible to evaluate the structural fire safety level.

Case study: Office Building

The case study treats with the steel-concrete composite structure for a public office building, already described above (see Figure 2). Each floor can be considered as a compartment. The compartment is open space (576 m2), with 12 windows 5.0 m width and 1.50 m height. The enclosure material has a density of 2000 kg/m3, a specific heat of 1113 J/kgK and a thermal conductivity of 1.04 W/mK. The possible types of fire action are both localized fires and generalized fire. The first type can be dangerous for some structural members, the second one can be dangerous for all the structural elements in the compartment (see Figura 1).

Results

The analyses developed confirm that the Fire Safety Engineering allows the structural fire behaviour through advanced computational models applied to both fire and structure to be evaluated. A natural fire is characterized by a heating phase and by a cooling phase. The thermal gradient in structural elements produced by the cooling phase is opposite to that produced by the heating phase. During the heating fire exposure the structural behaviour is non-linear and the plastic strains can be achieved in the structural elements; for this reason, the structure during the cooling phase is different from the original structure. Therefore, after the cooling phase the stresses and the forces in the structural element can be different from the ones before the fire exposure. The stresses and the forces induced by constrained thermal deformations may cause structural collapse; however, they can not
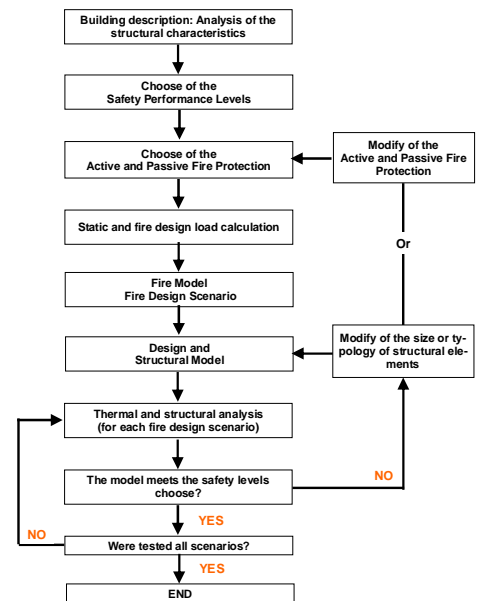
Figure 1: Fire Safety Engineering: Layout.
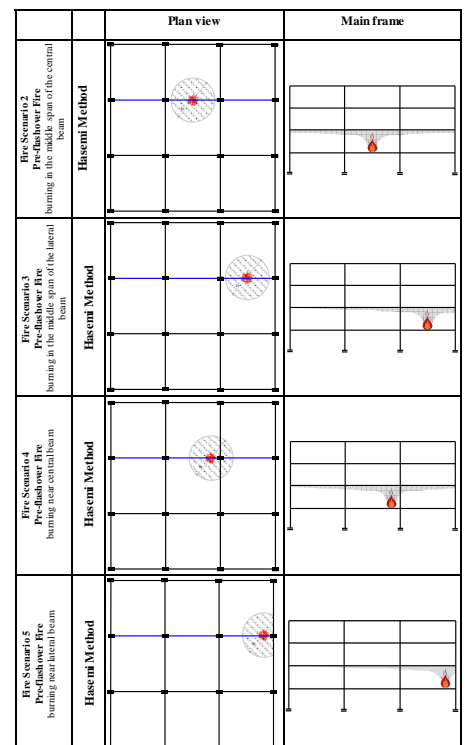
Figure 2: Office Building: Design Localized Fire Scenario.

fully controlled by the prescriptive approach, as this approach is based on the assumption of a standard fire curve which increases unrealistically. Note that the generalized fire scenario, represented by parametric fire curve (scenario 1), is in this case the most dangerous in terms of maximum temperatures achieved in the structural elements exposed to fire action, as expected.

The analyses confirm that the study of further scenarios is however necessary to take into account the effects of localized fires, which may led to partial collapses or damages with consequent risks for the intervention of Fire Brigades.

Case study: Open Car Park

For car parks structures, Italian prescriptive code requires that the load bearing function is maintained during 90 minutes of fire exposure (R90). This resistance time can be very onerous for the steel structures. The car parks are often characterized by extensive natural ventilation in each floor, and for this reason they are called open parking. This feature provides positive effects on the structural behaviour under fire situation, encouraging the use of steel structures. Recently in Europe several experimental fire tests for assessing the structural behaviour of steel structures and steel-concrete open car parks were performed. The research project ended with the publication of a guideline for the definition of fire scenarios for open car parks (INERIS, 2001).

A design fire scenario is the description of the course of a particular fire with respect to time and space. It would typically define the ignition source and process, the growth of fire on the first item ignited the spread of fire, the interaction of the fire with its environment and its decay and extinction. The scenario of fire is strongly affected by the geometry of compartment and its opening conditions. Nevertheless, for the open car-park, the number of the most onerous fire scenarios is limited. In Guideline INERIS (2001) three most dangerous fire scenarios are defined, thus the fire scenarios of Figure 3 was used to asses the structural behaviour of the prototype built with steel and composite steel-concrete members. The analyses were performed with:
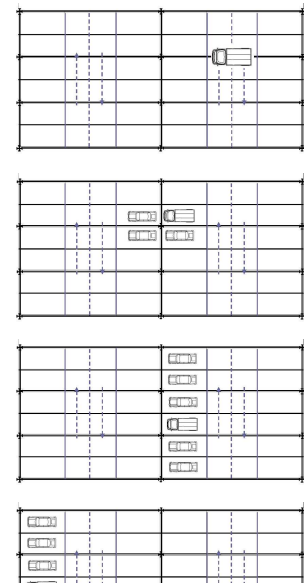
Figure 3: Open car parks: Design Fire Scenarios.

- Fire Scenario 1: characterized by the fire of a vehicle class 3 or, if necessary, a commercial vehicle at the centreline of the beam.

- Fire Scenario 2: characterized by the fire of four vehicles of class 3 (if necessary commercial vehicles) placed around a column with a initiation time delay for each vehicle of 12 min.

- Fire Scenario 3 and 4: characterized by a symmetrical spreading of the fire from the central car with a initiation time delay for each vehicle of 12 min.

Application to a real case

In this section an application of the "Fire Safety Engineering" for the assessment of structural resistance in case of fire is briefly showed with reference to the garages located on the ground floor of buildings in the CASE Project in L'Aquila. These garages are made with steel columns supporting the seismically isolated superstructure. In particular the car parks (Figure 4) examined have the following properties: 50 cm thick concrete slab on 260 cm height steel columns; the circular hollow steel sections have a device at the top allowing

Figure 4: Open car park in L'Aquila.

the isolator replacement. The thermo-mechanical analysis, performed by using the fire scenarios showed in Figure 4, allowed to affirm that the structures, and in particular the unprotected steel columns, attained the chosen performance level, thanks to the column over-strength in normal temperature condition.

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EXPERIMENTAL FIRE TESTS ON CONCRETE SLABS REINFORCED WITH FRP BARS

Research significance

Fiber-reinforced polymers (FRP) materials have several meaningful characteristics, such as high strength-to-weight ratios and resistance to corrosion, which are advantageous in the construction field. Recent progresses in research and technology of FRPs have led to reduced material costs and increased confidence in the use of polymers for a variety of civil engineering applications, as a lot of examples around the world can show. Nowadays several building codes (CAN/CSA 806-02, 2002; ACI 440.1R-04, 2003; CNR-DT203, 2006) are available for the design of concrete structures reinforced with Fiber Reinforced Polymers bars in place of traditional steel reinforcement, even if few provisions and no calculation model taking account of fire condition are suggested. ⬜Consequently FRP-RC employment is limited mainly to applications, where fire resistance aspects are not particularly meaningful. Thus, in order to improve the confidence in the use of FRP-RC members in multi-story buildings, parking garages, and industrial structures, the performances of these materials in fire situations must be evaluated. Therefore, to improve the knowledge of the structural response of FRP reinforced concrete members in fire conditions, experimental tests on nine concrete slabs reinforced with glass fiber reinforced polymer (GFRP) bars have been planned and partially performed.

Experimental program

The experimental tests were planned to evaluate resistance and deformability of the nine slabs in fire situations by varying (a) external loads in the range of the service loads, (b) concrete cover in the range of usual values (30-50mm), (c) bar anchorage shape (straight or bent) and length at the end of the concrete members, namely in the zone not directly exposed to fire (250-500mm). Note that zones not directly exposed to fire are often represented by mutual connections between members in concrete structures. The experimental program involved the design and fabrication of nine full-scale concrete slabs reinforced with GFRP bars (see Figure 8).

Figure 8: Slabs reinforcement grids before casting.

Three slabs S1, S2 and S3 were 3500mm long, 1250mm wide and 180mm thick. The concrete cover was 32mm, as estimated by reference to the centroid of the GFRP bars. The slabs S4, S5 and S6 were 4000mm long, 1250mm wide and 180mm thick; the concrete cover values were 51mm. The slabs S7, S8 and S9 were identical to slabs S1, S2 and S3, respectively, except for the shape of the longitudinal bottom bars at the end.

The concrete was identical for all slabs and characterized by calcareous aggregate (C35/45 according to EC2). E glass fibers and orthophthalic polyester resin were used by the manufacturer providing the FRPs. The experimental program, the main geometrical characteristics and the spacing of the reinforcement of specimens is summarized in Table 1.

Set	Slab	Length [mm]	Width [mm]	Thickness [mm]	Cover [mm]	Bottom bars (diameter/spacing) [mm]		Anchoring length [mm]	Bar shape
						longitudinal	transversal		
I	S1	3500	1250	180	32	$\Phi12/150$	$\Phi12/200$	250	Straight
	S2								
	S3					$\Phi12/225$			
II	S4	4000	1250	180	51	$\Phi12/125$	$\Phi12/200$	500	Straight
	S5								
	S6					$\Phi12/200$			
III	S7	3500	1250	180	32	$\Phi12/150$	$\Phi12/200$	250	Bent
	S8								
	S9					$\Phi12/225$			

Table 1: Fire test main parameters for FRP reinforced concrete slabs.

Experimental results

The slabs S1-S6 (Sets I and II) have been recently tested in a four-point bending scheme in fire conditions by exposing them to heat in a furnace (see Figure 9) according to the time-temperature curve of ISO834 provided in EN 1363-1 (2001). The results of these tests, widely reported and discussed in Nigro et al. (2009a,b and 2010a,b), are briefly described in the following. Three slabs of set II, characterized by concrete cover values of 51mm and anchorage length values in the slab unexposed zone of about 500mm, showed better structural behaviour in fire than three slabs of the set I, characterized by concrete cover values of 32mm and anchorage length values of about 250mm. Hence the importance of concrete cover in the zone directly exposed to fire for the protection provided to FRP bars, due to concrete low thermal conductivity was confirmed.
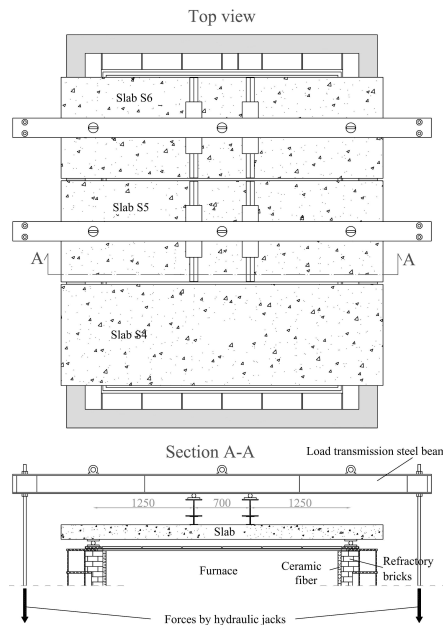
Figure 9: Test set-up – Slabs on furnace (dimensions in mm)

Figure 10: Slab S5 viewed from furnace after test. slab anchorage (a) 500mm; (b) 250mm.

Moreover the anchoring length of the FRP bars in the zone of slab not directly exposed to fire at the end of the members was crucial to ensure slab resistance once in the fire exposed zone of slab the glass transition temperature was achieved and the resin softening reduced the adhesion at the FRP-concrete interface.

In particular, the experimental outcomes highlighted that the failure of the concrete slabs can be attained due to the rupture of the fibres in the middle of the member (see Figure 10a) if a continuous reinforcement from side to side of the concrete element is used and zones not directly exposed to fire are guaranteed (i.e. 500mm, see Figure 10b). These zones, near the supports, are necessary to ensure adequate anchorage of bars at the ends once in the fire exposed zone of slab the glass transition temperature is achieved and the resin softening reduces the adhesion at the FRP-concrete interface. By contrast, the fire strength strongly decreases due the to pull out of the bars (see Figure 10c), if lower anchorage lengths of zones not directly exposed to fire (i.e. 250mm) are adopted.

Further developments

In a short time, the tests on the last set of three slabs (Set III), reinforced with bars bent at the end of the member in order to make better the anchorage of the bars within a short zone not directly exposed to fire (i.e. 250mm) will be performed. Based on the previous results, very good performances are expected for these slabs. Furthermore, a simplified method to evaluate fire resistance of concrete slabs will developed. A detailed modelling of RC slabs will leave out of consideration whereas the most meaningful constructive details necessary to attain good structural performances, will provided. In particular the design method will be mainly based on a simple calculating procedure taking into account the definition of the mechanical properties of bars at different temperatures, with particular attention to high values of temperature for which sudden decrease of strength with high uncertainty are expected for bars.

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FIRE ANALYSES OF COMPOSITE STEEL-CONCRETE FRAMES

Research significance

The advanced calculation models allow to evaluate the structural fire behaviour of single members, substructures and entire structures. The topic of the activities research is the application of advanced calculation models for fire structural analysis of composite steel and concrete frames.

The influence of some aspects of structural response developing during the fire exposure, generally neglected in the member analysis, on the assessment of the fire structural safety is pointed out, such as: indirect fire actions, large displacements, geometrical and mechanical non-linearities. Composite steel-concrete frames are designed with this purpose and are subjected to different fire scenarios.

Parametric Analysis

The considered frame presents a 24 meters overall length consisting of three equal spans and a 14 meters height consisting of four levels. The frame belongs to a three-dimensional structure with a square plan braced along the direction perpendicular to the studied frame. The columns are arranged with the axis of maximum inertia within to the plane of the frame. Beam-to-column connections ensure the rigidity of the nodes and they are assumed to be able to withstand the forces for a time at least equal to the time of fire resistance of elements transmitting the forces. The building was designed and checked under normal conditions for all load combinations required by the Italian Technical Standards for Construction. The seismic design of the frame was done in low ductility class and by respecting the capacity design criteria according to the Italian Code. The design of structures for earthquake resistance was conducted with reference to two different seismic zones (see Figure 1a), according to the Italian Code: (a) seismic zone 2 (a_g = 0.25·g); (b) seismic zone 4 (a_g = 0.05·g). The mechanical actions considered for fire design situation were defined by the exceptional load combination. The characteristic value of variable load was assessed according to the specific use of the office areas.
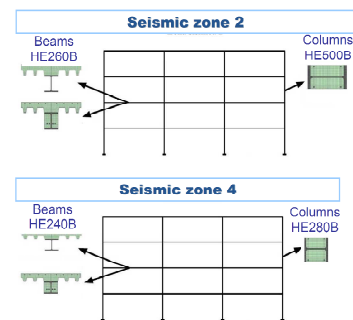
Figure 1: Steel-concrete composite structure.
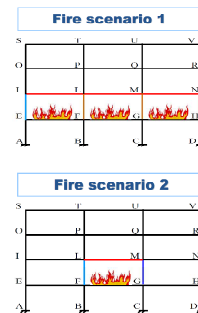
Figure 2: Fire scenarios.

The fire action is taken into account considering two different fire scenarios (see Figure 2):

a) Scenario 1 - assuming each floor as a single fire compartment, the fire involves only the first floor;

b) Scenario 2 - assuming the compartmentation of both each span and floor, the fire involves only the central span of the first floor. For both fire scenarios the thermal action is taken in accordance with standard fire exposure.

Results Discussion

The analyses are conducted by using the non linear software SAFIR2007, developed at the University of Liege (Belgium) and in Figure 2 are reported the main results. By the comparison between steel-concrete composite frames designed in two different seismic zones it is clear that, despite the different column overstrength resulting from the design criteria in normal conditions (capacity design and damage limit state), the two structures show similar collapse time in fire situation. It's due to the level of indirect actions caused by constrained thermal expansions which result, indeed, higher in the case of frames having more stiff columns. With regard to the substructure analysis, the main processes for defining the size and boundary conditions of the substructures have been highlighted. From the analysis it is clear that, in general, the reliability of the analysis depends on the substructure itself. Particularly significant is the case of substructures b2 and c2 for fire scenario 2, where the presence of horizontal translational restraint in nodes I and N allows to develop the catenary's action on the heated beam overstating the structural fire resistance.

Moreover, the comparison between single-member analysis and global analysis implies that single member analysis can lead to conservative results when the failure occurs on the beams, because the stresses on the beams are less affected by the effect of constrained thermal expansion. Instead, the single member analysis is not conservative when the failure is in the columns because the columns are important for both the second order effects and the effects associated with constrained thermal expansion.

Figure 3: Global Analyses Results

Figure 4: Substructures Analyses Results

Figure 5: Member Analyses Results

Future developments

These results are basically valid for the analysed cases. In order to extend these results to a significant class of framed structures a full parametric analysis need to be carried out. Moreover, to establish simple criteria for verification of composite structures taking into account the different described phenomena, a wide number of cases of analysis will be considered, by varying the main parameters of influence; appropriate consideration of the actual temperature trend during a real fire will be also performed.

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FIRE TESTS AND INVESTIGATION ON BUILDING MATERIALS AND STRUCTURES

Investigation of material properties at elevated temperature - Heat effect by natural building materials as stones and adobe

Numerous historical monuments or also modern buildings contain stone parts or often the whole structure is built of stone. Although natural stones are non-combustible building materials it doesn't mean that they don't suffer damages by heat effect. Fire and high temperature cause changes in the petrological and petrophysical properties of the building stones that often lead to stability problems. The knowledge of mechanical properties of natural stones is fundamental for conservation and restoration of the building stones of the monuments.

Natural stones are considered as less sensitive materials to fire. According to testing of different natural stone types (limestones, sandstones, tuff) at various temperatures, it has been proved that fire can cause rapid and irreversible physical changes (Hajpál & Török 2004, Hajpál 2008). These alterations negatively influence the strength and static behaviour of the whole monument (Hajpál 2008). Test results have shown that the compressive strength of various lithologies depends on the heating temperature. It can be observed, that the heating does not cause a decrease in the strength for all rock types.

Some sandstone and also the rhyolite tuff have higher strength after the heating at 900°C than at room temperature. The limestone types lost their strength only at elevated temperatures.Strength parameters and axial deformation of limestones do not change uniformly. The tests have demonstrated the differences of compressive stress and axial deformation with increasing temperature.Indirect tensile strength of limestones shows slight increase up to 150°C, which is followed by a decrease, while the tensile strength of sandstones and rhyolite tuff do not reflect a clear trend with increasing temperature.

Adobe and rammed earth are natural materials made of a mixture of fines (usually clay), sand, small stone fragments, organic material as fibre. In some adobe lime was also used. Significant number of adobe buildings have been damaged or lost in fire. To understand the behaviour of adobe under fire laboratory experiments were preformed (Alvarez de Buego et al. 2006). For the tests adobe cubes were prepared and heated at temperatures of 22, 150, 300, 450, 600, 900°C in an electric oven for a six-hour period. The test results were evaluated and compared to field and laboratory studies of burnt adobe structures. Colour changes, bulk densities and ultrasonic pulse velocities were analyzed as well as changes in mineralogy and micro-fabric. For most of the samples a decrease in density were documented after the heat shock. The strength parameters did not show uniform decrease, instead cubes that experienced 600°C show increased strength compared to specimens tested at 150, 300, 450°C.

The heating causes a colour change of stones and adobe. Not only colour but also other external signs of heat are observed. Limestone samples are cracked at lower temperatures while at higher temperature the samples collapsed or exploded. According to the thermal decomposition of carbonates this processes is dedicated to the formation of new mineral phases (portlandite).

The most important kind of decay of stones due to fire are scaling off, spalling, cracking, rounding off the edges. Fire can completely destroy ornaments and can damage carved forms. Fire damaged stones are often replaced by new ones (Hajpál 2000).

The firing model for earthen materials is different from that for stone materials, the effect of fire is more ubiquitous than for stones. The damaged zones are more severe in the interior part of the adobe than at stones. The heterogeneity and the characteristic manufacturing of earthen materials characterize their response to fire, mainly due to the addition of confined vegetable matter (straw), which creates an anoxic combustion. Firing can cause a positive change in adobe in terms of strength, since to a given temperature an increase in strength was observed under laboratory conditions (Alvarez de Buego et al. 2006).

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Fire resistance tests of building structures in accordance with the EN Standards

ÉMI Nonprofit Ltd. has a Laboratory for Fire Safety in Szentendre, Hungary, where we can make big fire resistance tests on horizontal and vertical non-load-bearing and load bearing building structures (walls, ceiling, pillars, etc.).

The appropriate temperature of the furnace chamber in the test furnace is provided by automatically controlled oil burners. The temperature in the furnace chamber is measured at more points by Ni-CrNi thermocouples. In accordance with the regulations of EN Standards on both sides of the model Ni-CrNi thermocouples can be installed during the test.

Measured temperatures and other data (pressure, distortion, etc.) can be also recorded.

The test results and observations are registered and after the test a test report will made. The fire safety grade classification and fire proofness of the investigated structure can be given.

References:

Part 5, Section I/4 of OTSZ (National Fire Safety Code)

The Decree 9/2008 (II. 22) ÖTM

MSZ EN 1364 and MSZ EN 1365 Standards

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BEHAVIOUR OF R/C SECTIONS, ELEMENTS AND STRUCTURES EXPOSED TO FIRE

Determining the fire response of structural elements and their assemblies is a complex problem of nonlinear analysis in which the strength and the stiffness of the elements as well as the inner forces are continuously modified. To solve this problem the computer program FIRE was developed. The program was verified on the bases of the experimental investigation results available in literature. This first [1] paper describes the analytically achieved results for the fire resistance of centrically loaded RC columns. The influence of: element geometry, concrete cover thickness, steel ratio and intensity of axial force are analyzed. Four RC beams, exposed to different fire models are analyzed too, and the predicted results are compared with those experimentally achieved by other researchers. Today, as a result of many years of investigations, there are three basic methods for determination of fire resistance of structural elements and their assemblies. The oldest method is the performance of a fire test of loaded elements, in compliance with the national regulations and standards, or comparison of the elements with the results from already performed tests on similar or identical elements. The second method implies the use of empirical formulae that are based on the results from performed fire tests and holds for a certain combination of: structure, material and protective coating. The third method represents an analytically elaborated approach to design elements with a predefined fire resistance and it is based on the principles of structural mechanics and theory of heat transfer. The solution technique used in FIRE is a finite element method coupled with time step integration. The used analysis procedure does not account for the effects of large displacements on equilibrium equations. To define the fire response of reinforced concrete structure is thus a complex nonlinear analysis problem in which the strength and stiffness of a structure as well as internal forces continually change due to restraints imposed by the structural system on free thermal expansion, shrinkage, or creep. Because linear elements and frames are modeled as an assemblage of members connected to joints, the basic analytical problem is to find the deformation history of the joints when external loading at the joints   and temperature history within the members   are specified. Since only linear elements and two dimensional frames are considered, each joint has three degrees of freedom, two translations and one rotation. Likewise, there are two forces and a moment at each joint.

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FIRE AFTER EARTHQUAKE

Structures exposed to fire after earthquake is relatively new research area especially when reinforced concrete structures are considered. In the scope of the COST Action TU0904 we find an excellent opportunity to extend our research in analysing structural behaviour in very severe conditions of fire environment after survived earthquake. Plastic stress-strain earthquake response histories of: mildly, moderately or severely damaged RC structures will be preserved so that in the continuation of the analysis the damaged structures will be exposed to different fire scenarios.

Calculating structural response to fire after earthquake is a few step process: modeling the structure including nonlinear analysis options, choice for earthquake analysis scenario, seismic nonlinear analysis (pushover or dynamic time history), fire hazards analysis to identify all possible fire scenarios, thermal analysis to calculate temperature history in each member, structural analysis to determine forces, stresses and deformations to estimate whether local or global collapse would occur during any of the fire hazard scenarios. The seismic excitation induces damage and lateral deformation provoking additional stresses in the frame due to the moment caused by the P-Δ effect. Structural members and joints are also weakened by the cyclic inelastic deformation, causing stiffness and strength degradation. Once the earthquake-induced damage in the structure is determined, the damaged structure is subjected to a fire scenario, which involves fire hazard analysis to determine the time history of fire growth and spread and stress and collapse analysis of the structure but also to analyse no-collapse conditions and cooling after fire.

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FINITE ELEMENT MODELLING OF LAP SHEAR RIVETED CONNECTIONS IN FIRE

Ancient metal structures represent an important architectural and historical heritage in Italy. These structures are generally affected by a spread damage state mainly due to corrosion and structural inadequacy. In particular, recent research carried out by the authors showed that riveted connections represent the weaker elements of these structures. To characterize their mechanical behaviour under actual service loads and under exceptional actions, like fire, a wide experimental-theoretical study is still ongoing, in collaboration with Italian railway society (RFI). Indeed, the basic modelling issues are presented and discussed and the preliminary fire modelling issues are introduced. With this regard, a highly detailed three-dimensional (3-D) finite element (FE) model has been created using the ABAQUS software. To characterize the mechanical behaviour of riveted connections under actual service load, the 8-node brick continuum element C3D8R was adopted for modelling both rivet and plates. The material stress-strain relationships for the rivets and plates have been obtained starting from the relevant experimental test on materials. The plasticity behaviour was based on the Von Mises yield surface criterion. Large deformation effects have been considered. The rivet clamping was also taken into account. Finally, the load pattern has been simulated by applying a relative displacement between the two opposite terminal ends of each connected plates. The response of the finite element model was compared with the experimental results. The load-displacement curve obtained from numerical simulation is in a good agreement with experimental results in terms of stiffness and strength.
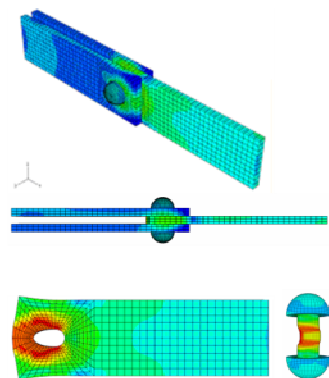
Figure 1: Predicted collapse mechanism of S16-10-1
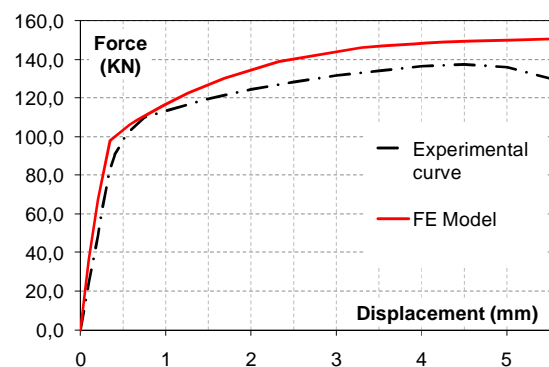
Figure 2: Numerical vs. Experimental response curve

This calibrated model has been updated to simulate the fire condition. This implied the modification of the material, mesh and contact properties. Indeed, the material properties at the elevate temperature were determined from the engineering stress-strain relationship using nonlinear material curves recommended in Eurocode 3, Part 1.2. The expansion coefficient, specific heat, and conductivity were also defined, and reduced according to EC3 when temperature increases. The Stefan-Boltzmann constant and the absolute zero temperature were also defined in Abaqus. Both the rivet and the plates were re-meshed using a 3D 8-node, thermally coupled brick element (C3D8RT). Once more large deformation, and geometric and material non-linearity have been taken into account. A thermal load was also added to apply the fire condition. The amplitude was set equal to the temperature-time curve given by the Eurocode 1 Part 1.2. The heat transmission due to radiation from the ambient where the fire develops to the external surfaces of the connection was also modelled.
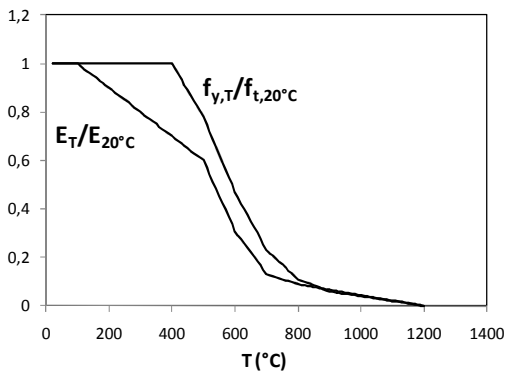
Figure 3: Mechanical properties of steel in function of temperature.
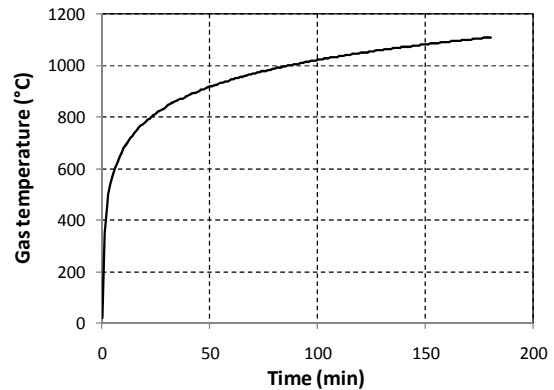
Figure 4: The applied fire (time-temp. curve given by the EN 1991 Part 1.2)

The temperature versus time behaviour of lap joints shows that until 500°C the strength and the deformability of the material is almost the same of the one at the ambient temperature. After about 5 minutes, the temperature overcome 500°C, and a great reduction of the connection response is noted. This behaviour advised that the lap shear joint worked until 500°C, that correspond to an increment of the displacement of 5%. After this time (about 5 minutes), the connection failed due to the reduction of its mechanical characteristics. However, further effort are necessary to improve the fire model especially for what concerns the interaction definition such as the Coulomb friction in contacts.
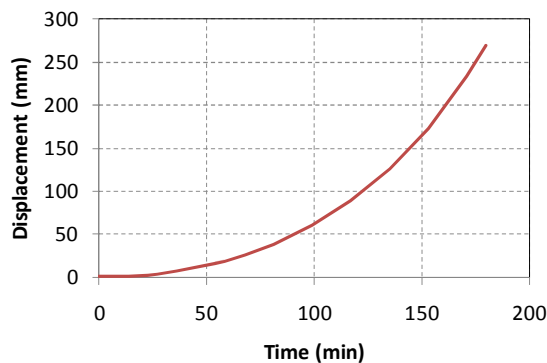
Figure 5: Time-Displacement curve of lap shear joint to fire

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COMPUTER SIMULATIONS OF STRUCTURES IN FIRE - VERIFICATION AND VALIDATION

Widely spreading implementation of computational methods in many fields of research and technology including studies on structures subjected to elevated temperatures, raises questions about the predictive capabilities of computer simulations. There are many contradictory opinions about the reliability of computer predictions [1]. Consider G. Box's well-known statement: "Essentially, all models are wrong, but some are useful" [2]. Nowadays verification and validation (V&V) is recognized as the primary method for evaluating the confidence of nonlinear computer simulations and of the mathematical model underlying them [3]. Recently, there has been a lot of attention dedicated to V&V methodology, with much research (see [4] for a review of this literature), workshops [5], and the first guides and standards published as the result (see [6-9]). There are two perspectives for V&V: that of code developers and that of analysts (users of the codes). In the software V&V, a code is a customer whereas in the model V&V the whole modelling process for a specific physical problem is considered. The code developers are more involved in code verification, while the analyst's responsibility is more oriented towards (experimental) validation.

Verification

Verification is supposed to deliver evidence that mathematical models are properly implemented and that the numerical solution is correct with respect to the mathematical model. Due to the high complexity of mostly nonlinear problems that are practically important for fire engineering, such verification can be conducted only empirically using "a posteriori" approach where the reasoning is based on the experience coming from repeated calculations. A standard example is the posteriori error estimation based on numerical results for different mesh resolutions. In the literature, verification is subdivided into two parts: code verification that primarily belongs to software developers and computational verification addressed to analysts (code users) [9]. According to AIAA [7], code verification can be conducted through tests of agreement between a computational solution and four types of benchmark solutions: analytical, highly accurate numerical solutions of an ODE or PDE problem, and manufactured solutions [10]. In contrast to numerical solutions used in the validation stage, the numerical solutions applied for verification can represent mathematical models with little physical importance.

Validation

Experimental validation is the final check to reveal possible errors and to estimate the accuracy of the simulation. [9]. Possible disagreement can be caused by the differences between mathematical and physical systems, the differences between computerized and mathematical models, and the distinction between a physical system (our concept of it) and the subject of an experiment used for validation [4]. The soundness of an experiment as a source of data for validation depends also on the relationship between the application and the validation domains [11]. The application domain defines the intended boundaries for the predictive capability of the computational model. The validation domain characterizes the representation capabilities of the experiment. When a complex system is modelled, there is a need for many validation experiments capturing different physical aspects of the system (e.g., different loading scenarios, mechanical and thermal boundary and initial conditions). The ideal situation, possible only for simple systems, is when the validation domain completely overlaps the application domain. This means that the available set of the validation experiments covers all possible parameters defining the computational model within its intended application. When complex systems are analyzed, it is sometimes infeasible or even impossible to conduct all necessary experiments to verify all features of the computational model. An example of such a situation is the global analysis of structures in the fire [12].

There have been only a few full-scale experimental fire tests (i.e., the Cardington [12] or Mokrsko [13] tests) conducted so far, but there are numerical capabilities for such complex analysis. The extreme, theoretical situation is when all possible or available experiments are too far from the application of interest and there is no overlap between the validation domain and the application domain [11]. The credibility of such a computational model, validated only through extrapolation, is obviously much smaller. To improve the predictive capability of computation in such cases, hierarchical validation is introduced where closer correlation of the domains is possible for lower-level experiments and then the gained confidence is extrapolated to the global model.

As stated before, the experiments may have many limitations, and practically the number of validation experiments is always limited. The tests conducted on large-scale and complex systems, on the one hand, are expensive or even infeasible and, on the other hand, are less useful for validation due to their complexity and too many uncertainties encountered at the same time (e.g. space and time distribution of temperatures). Even in supposedly simple experiments, there is usually a range of uncertainties for the input such as, for example, thermal and mechanical boundary conditions. To optimize the validation activities, application of the validation hierarchy is recommended [14]. In this approach, the experiments for the considered system are usually divided into three or four levels (tiers) representing different degrees of complexity. Such division can be done conceptually in different ways depending on the type of problem [10]. The tests classified to different levels can represent different portions of the physical system but, more importantly, capture different portions of the physics.

Validation and calibration

During the model development, the problem of modelling uncertainties is commonly treated using calibration. The idea of the calibration procedure is to establish the quantities of modelling parameters that give the model's response closest to the actual experimental data. The calibration is performed through comparison between an experiment and repeated calculations with modified input parameters. It is often pointed out that the calibration procedure should not replace validation but be a part of it and that the calibration should be minimized to only unmeasured input quantities [11]. It can happen that due to superimposing of errors we can get good correlation between experimental and numerical results for a wrong model defined by incorrect input parameters. Often, such a situation can be detected when the model is used for a different case with changed input conditions. Also, a complex model with only some of the input parameters "correctly" calibrated should give a response different from the experimental data due to the indetermination of other parameters. This is why validation based on more than one experiment is more reliable.

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BEHAVIOR OF RC ELEMENTS IN CASE OF FIRE

Determining the fire response of structural elements and their assemblies is a complex problem of nonlinear analysis in which the strength and the stiffness of the elements as well as the inner forces are continuously modified. Mainly, three groups of nonlinearity source can be identified: nonlinear distribution of temperature thru the element thickness, nonlinear temperature-dependent material properties (thermal and mechanical) and nonlinearity due to reaching of strength capacity.

Behaviour of RC beams under different fire scenarios

Performance assessment of concrete elements in case of fire is carried out with respect to a standard heating curve developed in a fire resistance test furnace. This heating regime is defined purely in terms of a temperature-time curve, originally conceived as being representative of the development of a fire in a standard living room, and expressed in essentially identical form in a number of standards, both internationally, i.e. the ISO-834 fire curve, and nationally, i.e. the BS-476 curve in the UK, ASTM E-119 in the US. Other fire curves, (short duration-high intensity or fire curves with decay phase) exist which is intended to replicate the temperature developments in other assumed scenarios, and in some cases they can be more realistic compared with the standard fire curves. Temperature distribution per height and over time for one reinforced concrete beam element is analyzed for two different fire scenarios, ISO-834 fire curve without and with two hours decay phase which starting 60 minutes from the fire beginning. Results from analysis show the big difference in temperature distribution along the section height, especially in the time of cooling phase.

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Coupled Thermal - Stress Analysis

The program FIRE (Cvetkovska 2002) carries out the nonlinear transient heat flow analysis (modulus FIRE-T) and nonlinear stress-strain response associated with fire (modulus FIRE-S). The solution technique used in FIRE is a finite element method coupled with time step integration. The modulus FIRE-S takes in to accounts the dimensional changes caused by temperature differences, changes in mechanical properties of materials with changes in temperature, degradation of sections by cracking and/or crushing and acceleration of shrinkage and creep with an increase of temperature. Four RC beams, exposed to different fire models were analyzed, and the predicted results are compared with those experimentally achieved by other researchers. Two beams were tested using the ASTM E119 fire exposure and another two were exposed to a short duration, high intensity (SDHI) expose.

The approach used in FIRE provides better agreement between the calculated and experimentally achieved deflections in case when ASTM fire model is used, but that is not a case during the cooling phase, when beams are subjected to SDHI fire model. The effect of creep at elevated temperatures in the program FIRE is involved by the temperature dependent stress-strain relationships for concrete and steel, recommended

in EC2. They are defined while specimens are subjected to ASTM E119 (or ISO 834) fire model, so they are not adequate for SDHI fire model.

The model proposed is capable of predicting the fire resistance of reinforced concrete structural elements with a satisfactory accuracy.

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Axial Restraint Effects on Fire Resistance of RC Beams

The various support conditions can have a big influence on fire resistance of reinforced concrete elements. Increasing of temperature, initiate elongation of structural elements, this can lead to the initiation of internal forces if they are restricted.
Two different support conditions (pin-pin and fully fixed) were used to model structural elements with various level of axial restraint. These beams were exposed to the ISO-fire curve without decay phase. From the obtained results can be concluded that increasing of axial spring stiffness increases the induced axial forces and fire resistance of the element and decreases the maximal vertical deflection.

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FIRE FOLLOWING EARTHQUAKE

Fire following earthquake is probably one of the most concerning hazards in both urban and industrialized areas. It can be looked at as a relatively low probability event characterized by extremely high consequences. Records from historical earthquakes show that sometimes the damage caused by the subsequent fire can be much more severe than the damage caused by the seismic action itself, this being true for both single buildings and whole regions (Scawthorn et al., 2005). Therefore, the behaviour in fire of structures, which have been damaged by earthquakes, represents an important investigation field, since the earthquake-induced damage may lead to a structure which is more vulnerable to fire effects than the undamaged one. In the perspective of resistance to the fire following earthquake, the relevant effects of the earthquake may be both non-structural and structural, the former ones being related to the damage to protection systems and facilities and the latter being related to the intrinsic resistance of the structure.

Post-earthquake fire resistance of steel and composite steel-concrete frames

Studies on the fire resistance of steel structures damaged by earthquakes have been carried out (Della Corte and Landolfo, 2001; Della Corte et al., 2003a, b). In those studies, both steel portal frames and multi-span multi-storey moment resistant frames were considered, with the aim of determining the fire resistance rating reduction of frames as a function of the maximum residual inter-storey drift angle and the seismic intensity. The work was developed in two main phases: 1) Dynamic time history seismic analyses, aiming to identify the type and intensity of earthquake-induced damage; 2) Fire analysis on the structural configurations distorted due to the seismic damage, carried out by means of an ad-hoc software. With regard to the simple portal frames, abaci were developed for computing the fire resistance rating reduction at increasing levels of residual storey drifts. With regard to the multi-storey frames, the effects of the seismic design and of the structural system layout were assessed, and the identification of the type of collapse mechanism in fire, exhibited by both the undamaged and the earthquake-damaged structures, was obtained.

The fire following earthquake topic was faced up also within the COST C12 European Cooperation Programme titled "Improving buildings' structural quality by new technologies". In particular, the Working Group 2 (Chairman: F.M. Mazzolani) was devoted to the study of the "Structural integrity under exceptional loads". The output of this work was summarized in a paper on the structural effects of fire following earthquake presented by Della Corte et al. (2005) at the COST C12 Final Conference, held in Innsbruck, Austria, on 20-22 January 2005. The interest in the topic was later confirmed by the COST C26 European Cooperation Programme titled "Urban Habitat Constructions under Catastrophic Events" (Chairman: F.M. Mazzolani), where a full Working Group (No. 1) is devoted to the "Fire design". During the COST C26 Workshop held in Prague on 30-31 March 2007, a paper was presented by Faggiano et al. (2007). The work aimed at carrying out the structural analysis under fire of earthquake-damaged structures through the following steps: 1) Seismic pushover analyses under horizontal loads of structures subjected to constant vertical loads, aiming at the damage identification; 2) Definition of the performance levels, correlating seismic intensity and damage extent; 3) Fire analysis on the damaged structures. In this study, portal frames made of steel were considered and the attention was focused on: 1) the evaluation of the fire resistance of the portal frames with relation to the geometrical span-over-height and overstrength ratios of a structural member; 2) the evaluation of the effect of the seismic-induced damage on the fire resistance and the collapse mode of the study structures. During the COST C26 Workshop held in Malta, on 23-25 October 2008, studies on the fire following earthquake risk management and structural analysis and design were presented (Faggiano et al., 2008a, b).

More recently, within the first Italian research project ReLUIS, research line no. 5 "Steel and composite structures", both analytical and experimental studies on the fire resistance of beam-to-column joints pre-damaged by earthquake actions have been carried out (Alderighi et al., 2008; Ferrario et al., 2007a, b; Pucinotti et al., 2008). A multi-step approach was followed, consisting in: 1) application of a cyclic inelastic loading history to the specimens; 2) fire tests on the damaged specimens; 3) numerical simulations of these tests by means of 3D finite element models; 4) numerical analysis of moment resisting frames.

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BEHAVIOUR OF ALUMINIUM ALLOY STRUCTURES UNDER FIRE

Research significance

The prediction of the mechanical response of aluminium alloy structures exposed to fire is complicated for two principal reasons: on one hand, the intrinsic difficulty of developing accurate structural analyses in post-elastic field, taking correctly into account the mechanical features of the basic material, such as the strain-hardening and the limited deformation capacity; on the other hand, the inadequate knowledge of the material behaviour under high temperatures. The methods of structural analysis in fire conditions should take into account the influence of the material constitutive law and thus of the kinematic strain hardening on the global behaviour of the structure.

Mechanical features of aluminium alloys at high temperatures

Common aluminium alloys melt at about 600°C and loose the 50% of their original strength at about 200°C. The alloys in the work hardening state (H) and the ones being in the hardening state by means of heat treatment (T) exhibit a relevant loss of strength with temperature, which is of about 70-80% at 250°C. Besides, the alloys in the annealed state (O) show a less significant decay of strength, which is of about 30-50% at 250°C. Heat treated and work hardened alloys (types T and H) are characterized by ultimate strength remarkably larger than the alloys in the annealed state (type O), only up to temperatures of about 100-150°C. At ambient temperature annealed state alloys (type O) present strain hardening ratio ($f_t/f_{0.2}$) about twice larger with respect to the heat treated and work hardened alloys (types T and H), such difference strongly reduces as far as the temperature increases, starting from temperatures of about 100-150°C. In addition, tempering and plastic working processes improve the material strength, but in the meantime they reduce both the effect of the strain hardening and the extent of the ultimate elongation (ε_u), which experiences a revival with the increase of the temperature.

From further data available in literature, it comes out that the resistance of the aluminium alloys, given in terms of both conventional yielding stress and ultimate strength, decreases as far as the exposure time to an assigned temperature increases. On the contrary, the ultimate elongation, and therefore the material ductility, increases with the prolonged exposure to high temperatures.

Proposal of stress-strain relationships for aluminium alloys at high temperatures

In order to interpret correctly the evolution of the mechanical characteristics of the material with the temperature, it would be possible to apply the Ramberg and Osgood model, whose *n* exponent measures the strain hardening of the alloy, ruling the shape of the curve in the post-elastic field. The extension of the Ramberg - Osgood relationship to high temperature is based on the introduction of the variation law with the temperature of all the relevant mechanical parameters, such as $f_{0.2,T}$, $\varepsilon_{u,T}$ and $f_{t,T}$.

For every alloy the values of the strain hardening factor *n* obtained at different levels of temperature, included the ambient temperature, have been provided (Figure 1). In order to evidence the influence of the mechanical properties on the strain hardening factor *n*, the value obtained considering the actual variation of the single mechanical parameters with temperature (n-analytical), is compared with the n values obtained taking the ultimate elongation as a constant and equal to the value at ambient temperature (n-ε_u=cost) and the constant value of n at ambient temperature.

It should be observed that for all the alloys the n value for high temperatures is remarkably different with respect to that one obtained at ambient temperature. Furthermore the *n*(T) relationship does not present a single trend for the different examined materials. In particular, for not treated materials (type O) it can be

noted that at increasing temperatures the strain hardening factor exhibits an increment higher than 50% with respect to the value at room temperature. On the contrary, for treated materials (H and T types) the *n* value is higher than the corresponding value at ambient temperature, only up to a temperature of about 200°C, beyond which there is a reversal trend, with values of the n factor lower than the ones at ambient temperature. Moreover it can be observed that the variation of the elongation at collapse ⍰$_u$ with the temperature has not a significant influence on the strain hardening factor *n*. As a consequence, in order to simplify the mathematical expression of the strain hardening factor, the ultimate elongation of the material could be actually taken constant and equal to the one at ambient temperature. Some numerical cases have been developed by the authors showing the effect of the material strain hardening at high temperatures, which should be actually taken into account for a correct interpretation of the resistance of aluminium structures.
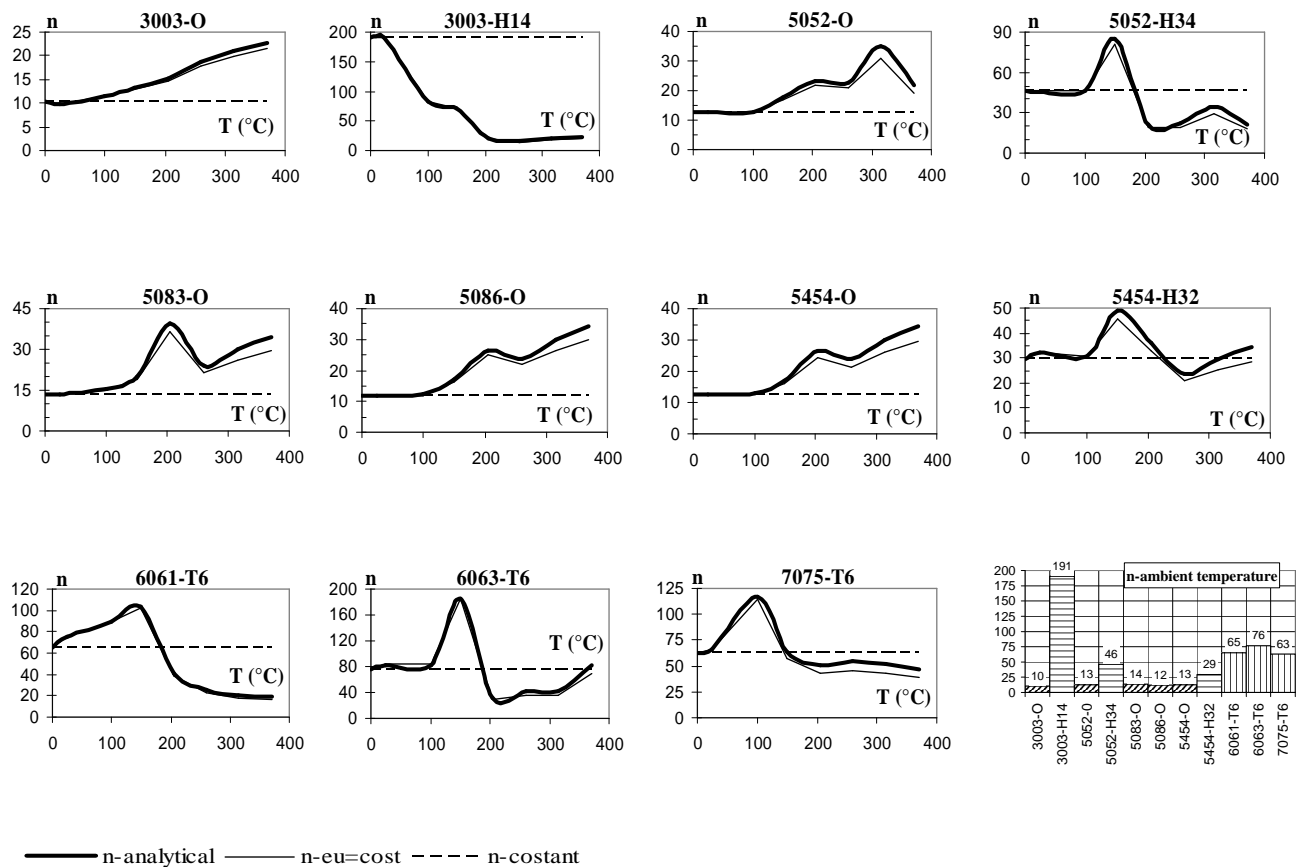
Figure 1: The strain hardening factor n as a function of temperature.

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STEEL COLUMNS IN FIRE

Behaviour of structures in case of fire is usually strongly affected by primary and secondary thermal effects which can substantially reduce the structural robustness. The structural analysis can be conducted on global level or limited to selected important structural components such as columns or connections. The analysis of isolated structural members is practiced very often in experimental studies which are usually based on the standard furnace tests on structural elements, often represented with reduced scale specimens. The same tendency dominates for numerical investigations and especially for the analytical simplified procedures which are developed for the design practice.

On one hand buckling of columns subjected to fires can be the primary cause of failure in framed structures. On the other hand, the structural performance of columns in fire depends on many conditions and can experience different scenarios. Some of these aspects are discussed briefly below with the references to the published research.

Behaviour of steel columns in fire

For steel columns and beam-columns in fires thermal effects can lead to premature buckling which can be local, distortional, flexural or lateral-torsional. The first thermal effect which needs to be considered is the reduction of mechanical properties of steel at elevated temperatures. At high temperatures, especially reaching above 350 C, the structural steel experience substantial degradation of material properties including elastic modulus and yield stress. These phenomenon is well described through usage of reduction coefficients which can be found at.

In case of confined fires, adjacent structural elements having much lower temperatures, can impose both axial and rotational restrains. In such cases the thermal expansion can generate additional loading in axially and rotationally restrained columns. Test results from a compartment fire in the eight-story steel-framed building at Cardington, have shown that the columns, which were heavily fire protected, were subjected to significant induced moments. The prediction of this additional loading is difficult as it depends on temperature distribution in both the column and the restraints (connections).

The effect of imperfections on buckling is magnified in fire conditions especially when a column is subjected to non-uniform temperature distribution caused by a local fire, partial insulation or due to partially damaged fire protection.

Unprotected steel columns have low fire-resistance due to the high thermal conductivity of steel. To protect steel structures against fire, the heat transfer between the structure and surroundings is reduced usually using spray-on fire protection. The behaviour of columns in fires with partially damaged fire protection has been investigated by many researchers mostly analytically and numerically. Much less experimental research is documented on these topic.

Some of the researchers point out that the creep governs the behaviour of steel columns above 400 C under general fire conditions. For some extreme cases, the temperature threshold can be as low as 350 C. For such cases it is suggested to conduct transient analysis in which creep is explicitly considered.

Simplified analytical procedures

The Eurocode 3 part 1-2 provides simple rules for determination of compressive resistance at elevated temperature. These rules are based on the concepts of standard design for members at normal temperature. The same cross-section classification can be applied without considering any change due to increased temperature. For members with cross-section classes 1, 2, and 3 the thermal effects are taken into account through reduction factors encountering the reduction of yield stress and modulus of elasticity

at elevated temperature. For compressive members with class 4 cross-sections it may be assumed that its compressive resistance is satisfactory if at time t the steel temperature θa at all cross-sections is not more than 350° C. Compression members with a non-uniform temperature distribution may be treated in the same way as members with a uniform steel temperature θa equal to the maximum steel temperature reached at time considered . Also according to the buckling length lfi of a column can be generally determined in the same way as for normal temperature design with the exception for the braced frames where under some conditions the buckling length may be taken as for a fixed column in an intermediate storey and as for a hinge –fixed column in the top storey.

Some of the researchers point out that the rules given by Eurocode 3 do not sufficiently take into account many important thermal effects and may be inaccurate in many practical situations leading to both too conservative uneconomical and unsafe values.

Using analytical models and based on the eigenvalue analysis for several selected cases Gomes et. al. developed alternative formulas to determine the buckling length at elevated temperatures for braced frames. They also showed that the buckling length of a steel column in a braced frame, indicated by the Eurocode 3 part 1-2 may be unsafe particularly in the case of fire in an intermediate storey.

Based on the results of a series of tests and calculations, Cabrita Neves et. al. proposed a simple method correcting the value of the critical temperature of steel columns free to elongate. The recommended formula takes into account the interaction with the adjacent structure, represented by elastic restraint to the thermal elongation.

Using an extensive set of calibrated finite element models and regression analyses, Wang et. al. developed simple equations for calculating critical temperatures corresponding to the column's buckling and failure. They considered uniformly heated, axially restrained steel columns with geometrical imperfections, subjected to axial compression load eventually combined with bending moments.

A practical design method for calculating the buckling and failure temperatures of restrained steel column under axial load or combined axial load and bending moment is presented in. Based on the results of extensive numerical parametric studies new design equations are adopted for calculation of the buckling temperature of a restrained column including the effect of additional compression force generated due to restraint thermal elongation.

Paper presents research work conducted on bi-axially loaded steel columns under fire conditions. The authors extended Rankine method governing the load-bearing capacity to predict the fire resistance of steel columns subjected to bi-axial loading under standard fire curve. Predictions from the proposed approach were compared with the computational results obtained using finite element program SAFIR.

Zeng et. al. proposed an analytical method to predict the fire resistance of a pinned-pinned steel column, taking into account the complicated creep strain, as well as the degradation of steel mechanical properties. The predictions are verified experimentally and numerically.

Experimental studies

Experimental tests are conducted usually following three scenarios. In the first scenario a specimen is kept under constant mechanical loading while the furnace temperature is increased. The objective of this test is to determine the failure mechanisms and critical temperatures, corresponding to buckling or column's failure. In the second scenario a specimen is firs heated and then loaded. Such tests could be used to find the ultimate mechanical loading for a specific temperature. In the third scenario both mechanical and thermal conditions are time dependent. This case take place for example If the column is axially restrained and additional loading is generated due to thermal elongation.

Tan et. al. conducted a research program on an experimental investigation to determine the failure time of unprotected steel columns subjected to various axial restraint ratios. The test results showed that axial

restraints, as well as initial imperfections, significantly reduce the failure times of axially-loaded steel columns. By contrast, bearing friction substantially retards column failure times.

An experimental study on axially loaded steel columns with partial loss of fire protection was performed by Wang and Li. Furnace tests were carried out under the ISO834 standard temperature variation for two steel columns protected with 20mmthickness of fire protection and with the damaged length equal to 7% or 14% of the total length. The experimental results are compared with calculations obtained using an analytical continuum model and finite element analysis.

Three companion papers present experimental tests and numerical parametric study on the restrained steel columns in fire. The first paper reports the results of two fire tests on steel columns axially and rotationally restrained by a connected beam. The columns are loaded with constant axial external load and by additional increasing and decreasing axial force generated in the restraining beam.

The extensive experimental programme for parametric investigation on the performance of rotationally restrained steel columns in fire is presented in papers and. As a part of steel frames, half scale steel columns were tested in fire under different values of axial and rotational restraints. Ali et. al represented also a method of estimating the effective length of fixed end (partial fixity) columns tested under fire.

The paper describes fire tests performed to investigate the mechanics and capacity of steel beam-columns subjected to non uniform heating with temperatures varying through the cross-section. Partially insulated wide-flanged specimens, loaded axially were tested vertically in a furnace following a realistic three-sided heating scenario adequate to a column on the perimeter of a building frame.

A series of fire-resistant steel columns were experimentally tested at specified temperature and under increasing loading reaching ultimate states. The effects of width–thickness ratios, slenderness ratios and residual stress on the performance of fire-resistant steel H-columns were examined. An analytical model and design guidelines were proposed for fire-resistant steel H-columns under elevated temperature.

Wang and Davies tested non-sway loaded steel columns, exposed to fire and rotationally restrained by two loaded steel beams. The mechanical loading was kept unchanged throughout the fire test in order to simulate a column with free thermal expansion. The objectives of these tests were to evaluate the effect on the failure temperatures of bending moments generated in the restrained columns.

Numerical analyses

A review of recently published numerical studies on the behavior of steel columns in fire shows some clear tendencies. In most of the work, commercial nonlinear FE programs are implemented, such as: ABAQUS, ANSYS, LS-DYNA. The most commonly applied is a geometrical and material non-linear finite element program SAFIR, developed in Liege especially for the analysis of structures submitted to fires. Less frequently self-developed FE programs such as FEMFAN2D or FINEFIRE are used. Beam element models dominate, and most of the considerations are confined to 2D subsystems. Numerous simplifications applied in the models are justified by the required limitation of the computational time and recourses. The numerical models are used as a tool for extensive parametric study, for verification of analytical models, as an addendum of experiments, and just for illustration of experiments.

Depending on the simulated test scenario, three types of analysis can be considered: structural, thermal or coupled structural-thermal. Structural stress analysis should be able to take into account strains due to elastic and plastic deformation and due to thermal elongation if coupled structural-thermal analysis is performed. Creep strains can usually be captured using transient analysis. Incremental, transient structural analysis should be based on explicit or implicit methods for time integration. Application of explicit methods in coupled structural-thermal fire analysis can be performed through controlling the time step, in order to produce quasi-static responses.

Coupling thermal and structural calculations in one numerical analysis is rare for structural fire engineering investigations. Usually thermal conditions are defined through constant or time dependent prescribed temperatures applied to selected nodes.

Huang et. al. presented a numerical study conducted on thermally restrained steel columns subjected to predominantly axial loads. The investigated parameters included the column slenderness ratio, axial restraint ratio, rotational restraint ratio, and axial load utilisation factor. Extensive investigation was conducted to study the creep effect on the development of stress and strain, internal forces and critical temperature of a column.

A numerical study of the behaviour of steel I-beams subjected to fire and a combination of axial force and bending moments is presented in. Program SAFIR was used to determine the resistance of a beam-column at elevated temperatures. The numerical results have been compared with those obtained with the Eurocode 3, part 1–2 (1995) and the new version of the same Eurocode (2002).

Computer simulations of 10 fire tests on restrained steel beam-column assemblies using five different types of joints are presented in a paper which depicts development and validation of detailed finite element model built of three-dimensional solid elements and dedicated for ABAQUS/Standard solver. The FE models are dedicated for numerical parametric studies on steel framed structures in fire.

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LARGE SCALE FIRE TESTS

Many aspects of behaviour occur due to the interaction between structural members in a structure exposed to fire and cannot be predicted or observed from isolated tests. Standard tests cannot predict global or local failure mechanisms that are a function of deformations and stresses caused by restraint to thermal expansion provided by the unheated portion of the building. Similarly standard tests cannot demonstrate alternative load paths mobilised through a redistribution of forces from heated to unheated parts of the structure. The large scale tests are performed on the real building or on the large parts of the structure. The fire load is often created by wooden cribs 50 × 50 mm of length 1 m from softwood or by gas burners. The variable mechanical load during the fire experiment is mostly simulated by bags filled by sand. Over the years many isolated member tests have been carried out. However, investigations involving the well documented full-scale tests under natural fire, which is summarised below, are limited.

Sprinklers and unprotected steel test

Sprinklers and unprotected steel test was examined by a series of four fire tests was carried out to obtain data for the second risk assessment. The tests were to study matters such as the probable nature of the fire, the performance of the existing sprinkler system, the behaviour of the unprotected composite slab and castellated beams subjected to real fires, and the probable generation of smoke and toxic products. This simulated a typical storey height 12 m x 12 m corner bay of the building. The test building was furnished to resemble an office environment with a small, 4 m x 4 m, office constructed adjacent to the perimeter of the building. This office was enclosed by plasterboard, windows, a door, and the facade of the test building. Imposed loading was applied by water tanks.

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140 William Street Office Building, BHPR/ENG/R/92/043/SG2C, BHP Research, Melbourne Australia, 1992.

Office compartment demonstration test

Office compartment demonstration test was constructed to simulate a section of a proposed steel-framed multi-storey building in Collins Street, Melbourne. The purpose of the test was to record temperature data in fire resulting from combustion of furniture in a typical office compartment. The compartment was 8.4 m x 3.6 m and filled with typical office furniture, which gave a fire load between 44 and 49 kg/m2.

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Open car parks test

Between 1998 and 2001, as part of an ECSC funded project, fire tests were performed on an open car park with a composite steel and concrete structure. A single storey composite steel-framed open car park was constructed specifically for full scale fire tests. The floor of the car park occupied an area of 32 × 16 m², which is equivalent to a 48 space car park and the storey height was 3 m. The structure was composed of: unprotected steel edge columns HEA180, central columns HEB200, composite beams: unprotected steel beams IPE 550, IPE 400 and IPE 500, connected to the composite slab, composite slab with a total thickness of 120 mm.

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Cardington laboratory

The Cardington Laboratory was a unique worldwide facility for the advancement of the understanding of whole-building performance. Most aspects of a building's lifecycle, from fabrication to fire resistance and explosions through to demolition, can be investigated on real buildings. This facility was located at Cardington, Bedfordshire, UK and consists of a former airship hangar 48 m x 65 m x 250 m.

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Cardington steel framed building

The steel test structure was built in 1993. It is a steel framed construction using concrete slabs supported by a steel decking in composite action with the steel beams. It has eight storeys (33 m) and is five bays (5 x 9 m = 45 m) by three bays (6 + 9 + 6 = 21 m) in plan. The structure was built as non-sway with a central lift shaft and two end staircases providing the necessary resistance to lateral wind loads. The main steel frame was designed for gravity loads and the connections, which consist of flexible end plates for beam-column connections and fin plates for beam-beam connections were designed to transmit vertical shear loads. The building simulates a real commercial office in the Bedford area and all the elements were verified according to British Standards and checked for compliance with the provisions of the Eurocodes. Seven large-scale fire tests at various positions within the experimental building were conducted; see Tab. 1. The main aim of the compartment fire tests was to assess the behaviour of structural elements with real restraint under a natural fire. The principal parameters of these tests are summarized in Tab. 2.

No.	Test	Fire compartment		Load	
		Size, m x m	Area, m^2	Fire	Mechanical
1	Restained beam	8 x 3	24	Gas	30%
2	Restrained frame	21 x 2,5	53	Gas	30%
3	Corner compartment	10 x 7	70	45 kg/m^2	30%
4	Corner compartment	9x 6	54	45 kg/m^2	30%
5	Large compartment	21 x 18	342	40 kg/m^2	30%
6	Office demonstrational	18 x 9	136	46 kg/m^2	30%
7	Internal compartment	11 x 7	77	40 kg/m^2	56%

Table 1:   Fire tests on steel structure in Cardington laboratory

No.	Org.	Level	Time to max. temp.	Reached temperature °C		Measured deformations	
				Gas	Steel	Maximal	Residual
1	BS	7	170	913	875	232	113
2	BS	4	125	820	800	445	265
3	BS	2	75	1020	950	325	425
4	BRE+SCI	3	114	1000	903	269	160
5	BRE	3	70	-	691	557	481
6	BS	2	40	1150	1060	610	-
7	CTU	4	55	1108	1088	> 1000	925

BRE – Building Research Establishment; BS- British Steel (now Tata); BRE+SCI with Steel Construction Institute; CTU – collaborative research proposed by Czech Technical University in Prague.

Table 2:   Summary of results from fire tests on steel structure in Cardington laboratory

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Cardington concrete framed building

The seven storey concrete framed structure in Cardington laboratory was designed on plane 30 x 22,5 m with height 25,2 m. The building represents a commercial office in the Bedford area. The fire experiment was focused to slim framed structures loaded by well defined mechanical load. The slab was mechanically loaded by 3.25 kN/m2 using sandbags. The timber cribs create a fire load 40 kg/m2, e.g. 720 MJ/m2.

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Cardington timber framed building

The fire tests on timber framed building were conducted under the project Timber Frame 2000. The structure was designed as light skeleton for the multi-storey residential buildings according to Platform frame system. Except of the large scale fire tests, which allowed the precision of the standard for fire resistance of timber structures EN 1995-1-2, there was an integrity test of building exposed to impact and explosion and smaller fire tests. At each floor were designed four apartments, the timber stairs and the lift well. The external load bearing walls were created by cladding of two pasteboards of thickness 12.5 mm and a OSB plate 9 mm. The internal frame with columns 38/89 mm in distance 600 mm were designed from timber of class C16. The space between the columns was filled by thermal insulation. In distance 60 mm in front of external walls was built a brick wall. The internal load bearing walls were designed a similar way as

the external ones. The cladding of internal wall created one pasteboard 12.5 mm only. Floor beams 38/225 mm each 600 mm were designed of timber class C16.

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Steel frame connections temperatures and forces

Unprotected steel floor 3.80 × 5.95 m fire test was carried out on a three-storey administrative building which was attached to a single-storey framed building of the Ammoniac Separator II in the Mittal Steel Plant in Ostrava, Czech Republic in 2003. The fire compartment was 3,80 × 5,95 m with a height of 2,78 m and was built on the second floor. The mechanical load was applied on the third floor. The total load, including self weight of the structure, was 5,7 kN/m2. Wooden cribs were used as the fire load, which created the fire load density of 1039 MJ/m2. Two fire tests were carried out on the building. The first, a localised fire test, was performed on 15 June 2006, and was set up to measure the temperature of the steel column and beams close to the centre of the fire. The second was a compartment test and was performed on 16 June 2006, and was designed to obtain the gas temperature in the fire compartment, the temperatures of the beams.

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Composite floor 12 x 18 m to collapse

The main objective of the fire test in Mokrsko were the temperatures of partially encased header plate connections, behaviour of castellated composite beams with the sinusoid openings Angelina, and beams with corrugated web of thickness 2.5 mm. The experimental structure represents one floor of the administrative building of size 12 x 18 m, with the high 4 m. The fire load was created by unwrought wooden cribs 35.5 kg/m2 of timber and it simulated the fire load 620 MJ/m2. The applied load by plastic bags filled by road-metal represents the characteristic value of the variable action at elevated temperature 3.0 kN/m2 and the characteristic value of flooring and partitions 1.0 kN/m2. The predicted resistance of the slab 60 min was reached in 62 min.

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Composite unprotected floor 8.735 x 6.6 m

Composite unprotected floor 8.735 x 6.6 m was tested under the FRACOF project the composite steel and concrete floor composed of four secondary beams, two primary beams, four short columns and a 155 mm thick floor slab. The test was evaluated to the application of the catenary action and simple design procedure in European design.

References:

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Composite unprotected floor 6.6 x 8.4 m

In the scope of COSSFIRE project specific composite floor 6.6 x 8.4 m was fire tested. For this floor, the cross sections of steel beams and steel columns were IPE270 and HEB200 of steel grade S235.The design of floor system was undertaken in accordance with the requirements of EN1994-1-1 for room temperature design of composite structures with a permanent load of 1.25 kN/m² in addition to self weight of the structure and a live load of 5.0 kN/m². The fire test was conducted with a load of 3.93 kN/m² which corresponds approximately to 100% of various permanent actions and 50% of live actions according to Eurocode load combination in fire situation for office buildings.

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Composite floor with cellular beams 15 x 9 m

Composite floor with cellular beams 15 x 9 m was tested acting in membrane action with large deflections. The slab was made of 51 mm deep profile of the Kingspan Multideck 50 type with a concrete cover of 69 mm on the profile, which makes a total depth of 120 mm. A steel mesh of 10 mm with a spacing of 200 mm in each direction made of S500 steel was used as reinforcement. It was located at a vertical distance of 40 mm above the steel sheets. The slab was fixed on all steel beams by means of steel studs on the upper flanges for full connexion. All connections from secondary beams to main beams and from beams to columns arc simple connections. Horizontal bracing was provided in 4 positions leaving the slab completely free of external horizontal restraint. The natural tire was created by a wood crib fire load of 700 MJ/m2 and the 9 x 15 m 110m survived the fire that peaked at 1000°C and lasted for 90 min.

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STEEL BEAM-COLUMN UNDER THERMAL GRADIENT

Beam-column is a term which is used to describe a structural member which is simultaneously subjected to an axial compressive force and a bending moment. This type of element is commonly met in steel frame buildings. A beam in such buildings tries to expand due to thermal loading that is induced to it, but the restraints prevent this expansion and as a result, a compressive force develops on the member, in addition to the bending moment in place due to the gravity load. Similarly, a possible expansion of a beam can cause additional moments to the column of the structure, apart from the axial force already imposed to it. Contemporary provisions of the Eurocodes assume a uniformly distributed temperature over the steel members for the estimation of their capacity. Such a hypothesis, for the members that are located on the borders of the fire room, may lead to disproportional results in relation to the true situation.

Combined axial-bending capacity of steel double-T cross-sections subjected to non-uniform temperature distribution

Eurocode produces higher values for the modulus of elasticity for the elastic region than the Ramberg-Osgood equation. This fact changes as the cross-section enters the plastic region where the R-O modulus of elasticity shows a more prominent hardening, a fact that makes the R-O seem more optimistic, especially, when the temperatures are not the highest that may develop during a fire. Using the EC relationship for the estimation of the axial load-bending moment capacity, it was found that the capacity envelope that EC 3 (Part 1.1 – cl.(6.36)) proposes may be conservative or non-conservative in relation to the real situation. Thermal gradient alters the capacity of the crosssection. The normalization of N-M values was made for the (constant) mean value of the temperature field. EC envelopes illustrate the capacities of the beam-column elements, assuming uniformly distributed temperatures. On the one hand, in the region where the accumulation of the points falls outside the safety envelopes, EC appears conservative, whilst in the opposite situation, the EC approach appears to be optimistic. Therefore, as the slope of the thermal gradient increases, so does the discrepancy between the EC capacity envelopes and the true ones.

As a conclusion, it can be said that:

- the region of safe operation of the cross section presents under that presence of thermal gradient shows a differentiation in shape that is not accounted for by the present regulatory framework;

- extensive parametric research is needed in order to obtain N-M interaction safety regions for the commonly used structural steel cross sections;

- the absence of a distinct hardening form of the stress-strain curve at elevated temperatures requires, to the authors opinion, a reconsideration of the concept of allowable stress so as to obtain the same safety margin with the low temperatures range.

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Determination of the K1 increasing factors of the stress-strain relationship for steel double-T cross sections subjected to non-uniform temperature distribution

EC3 proposes reduction factors $K\theta$ for the determination of the stress-strain relationship of steel at elevated constant temperatures . These factors give the effective yield strength, the proportional limit and the slope of linear elastic range according to the imposed temperature. In case of non-uniform temperature distribution, the use of the stress-strain relationship with the $K\theta$ factors derived from the maximum temperature seems to be conservative, whereas with those derived from the average temperature seems to be optimistic. Assuming the $K\theta$ factor of the maximum temperature on the cross-section and dividing it by a new K1 factor will increase the capacity of the steel member and be more realistically. The aim is to determine the increasing K1y factor of the effective yield strength and the increasing K1E factor of the slope of the elastic range for various types of steel double-T cross sections. To conclude; a) Extensive parametric research is needed in order to obtain the K1 safety regions for the commonly used structural steel cross sections; b) The use of the K1y factor of the effective yield strength can increase the capacity of the steel double-T cross sections at least 15% for $\Delta\theta > 100$ $^{\circ}$C; c) The present regulatory framework proposes the K1y factor = 0,7 for unprotected beams exposed on three sides, which seems to be very optimistic; d) The use of the K1E factor can increase the slope of the elastic range of the steel double-T cross sections at least 10% for $\Delta\theta > 100$ $^{\circ}$C.

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A SCIENTIFIC APPROACH TO BEHAVIOUR OF INTUMESCENT PAINTS

Intumescent paints or coatings are one of the products usually used in passive fire protection for structural uses; there are a lot of paint manufacters in the market working with different kind of paints or coatings for specific applications on steel, concrete, aluminium, wood or other structural materials. In the case of steel structures the main advantage relies on the capability to protect the steel from the high temperatures in a fire scenario without breaking the aesthetics of the steel and without increasing the self weigh of the frame.

The basic principle of the intumescent paint is that it reacts and it swells when the fire heats it, producing a layer of insulating material that can be between 50 or 100 times bigger than the initial dry thickness. This allows the steel remain at secure temperatures and avoid the collapse in fire scenario during some time. Typical values for fire ISO834 resistance are R15 to R60.

To evaluate the contribution to the fire resistance of structural members by intumescent paints, several tests are made with different specimens in official fire laboratories, in order to analyze the thermal and thermo-mechanic behaviour of the steel and the intumescent paints. From the test results, semi-empirical mathematics models are used to reproduce the same insulation that the intumescent paint produces, this allows relating the variables like time, temperature, section factor of the profile and the initial thick of paint, enabling to deliver technical characteristics of the product.

The procedure to make this fire test and the mathematic treatments done later is regulated in Europe for Euro norms as the ENV 13381-4 [1] [11] or its more up to date version and more specific for intumescent paints, the EN 13381-8 [2]. These standards define how the fire test must be performed, how the loss of the insulation effectiveness must be taken into account due to the stickability (ability of the intumescent layer to remain coherent and in position along the defined range of deformations), and furthermore several mathematical models are proposed by regression to assess the performance of the intumescent coating to calculate the necessary thickness to be applied in the structures [4] [5] [6] [7] [8] [9] [10].

Nowadays, the official fire laboratories that certify and accredit the paint from different manufactures, are using one of the methods defined in the standard ENV 13381-4 [1] or prEN 13381-8 [2] named "Numerical Regression Analysis". This method is very effective on reproducing the results from test specimens without the need to know about the thermal properties of the coating, and leaves on easy way to calculate the necessary thickness for a required fire resistance, but presents several inconveniences that make intumescent paints expensive:

Normally the numerical regression analysis is done taking 500°C as a maximum temperature for steel. This means that we are introducing too much paint in frames not very strongly loaded where the aspect ratio can be low.

Numerical regressions done for higher temperatures don't give accurate results for temperatures ranges below the maximum temperature considered.

Usually the official European fire laboratories don't want to deliver several linear regressions for different maximum temperatures from the same test. To do this, they want repeat the test and this is more expensive for the manufactures.

The numerical regression method only allows calculating the necessary thickness in cases where the fire curve considered is the normalized ISO 834 (the same one used in test).

In the standards there are other alternative methods that take less to obtain effective thermal properties of the paints from the dates of the test specimens. This makes possible to reproduce, in a more transparent

way and for all range of temperatures from 350°C to 750°C, the heating up of the profiles. One of these scientific methods is presented in the standard prEN 13381-8 [2] as "Differential Equation Analysis" (or Variable λp Approach).

This method uses the known differential equation for simple calculations models defined in the standard EN 1993-1-2 [3] to evaluate the temperature progress for internal steelwork insulated by fire protection material, and it uses the effective thermal conductivity (⬚p) as major parameter that includes the most of thermo-mechanical effects during the process of intumescence.

Although this method requires a bit more accurate tests in fire laboratories, it has the big advantage of making possible to calculate the necessary thickness of paint for all ranges of temperatures of steel. Furthermore, this method gives to engineers the thermal property (⬚p) that reproduces the temperature progress of the steel cross-sections by analytical approach in EN 1993-1-2 [3] or by finite elements analysis (FEA) in a profile with complex geometry.

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FIRE BEHAVIOUR OF BOLTED CONNECTIONS

The conventional approach of fire safety engineering uses prescriptive regulations to calculate fire resistance of single members according to ISO-fire curve. At present this approach is changing into a more performance based calculation. It becomes usual to calculate temperatures by realistic fire scenarios based on fire loads and ventilation conditions. Consequently it is necessary to calculate the structural behaviour on realistic scenarios as well. This must also take into account the interaction between members inside the structure instead of excluding one member and testing it in a controlled environment in a laboratory. When calculating a structure of more than one member, it is obvious to consider the connection behaviour.

It becomes important to gather more information about connection behaviour in fire situations. For this reason different research projects have been carried out in the recent years in Germany, which are fully or partially investigating connections in steel and composite constructions in fire. In the following, parts of different research projects are described, which are aimed at the connection behaviour.

Behaviour of high strength bolts in fire

While material behaviour of structural members like beams and columns is well known even for high temperatures, there is still a lack of knowledge in high strength bolt materials. Especially the fire behaviour of high strength bolts can be worse than behaviour of normal strength bolts or steel members because of the strengthening process. For this reason it is necessary to develop methods to simulate the behaviour of high strength bolts in fire conditions.

An actual research programme deals with the fire behaviour of grade 10.9 bolts, which are the most common high strength bolts in Germany. Test series at different temperatures have been arranged for real bolts and test specimen consisting of bolt material. The load direction is varied to cover tensional and shear failure of the bolts. In addition the failure of bolts after cooling is tested to predict their behaviour after a fire.

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Behaviour of slim-floor-beams in fire

Slim floor beams consist of different shaped cross sections, which are fully or partially integrated into a concrete slab. This kind of beam provides a longer fire resistance time compared to bare steel beams. This is because high temperatures in fire situation are kept away from the steel parts by the surrounding concrete for a certain period of time. In many cases it is possible to leave the fire exposed steel parts of the slim floor beams unprotected, if only a short fire resistance time (e.g. 30 min) is needed.

To increase the fire resistance time of different slim floor beams, a research project has been conducted recently. Aim was to increase the fire resistance by activating reserves of the static system instead of protecting the fire exposed steel parts. This was done by calculating the moment capacity of internal column connections, which are calculated as pinned at the ultimate limit state calculation. For the reason of the partial concrete encasement of the connections, their temperatures and hence their static behaviour had to be calculated using finite element simulation. It was found that even the very small moment capacity of the tested internal connections can significantly increase the fire resistance time.

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Fire behaviour of connections consisting of high strength bolts

The fire behaviour of connections in steel and composite structures depends on the bolt behaviour but also on many further parts of which the connection consists. For example the thickness of a fin plate or the flange of a connected column can have large influence on the moment-rotation-relationship. At ambient temperatures it is possible to use the component method to predict the connection behaviour. In case of fire, there is no validated method at the moment. For this reason it is necessary to use finite element modelling to investigate the connections more in detail.

An actual research project aims at the development of validated finite element models for two different types of connections containing high strength (10.9) bolts. The models will be validated by two large scale tests at internal beam to column connections. Using the validated numerical models, parametric studies will be conducted to predict the effects of different modifications to the connection geometry.

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No references at the moment; will be added

Fire performance of external semi rigid composite joints

In a recently finished research project, the fire behaviour of unbraced frames has been investigated. The main aim was to design composite frames that do not need to be braced by walls or another kind of wind bracings.

One main task was the calculation of the behaviour of the external joints between the columns and the beam. To investigate the fire performance four fire tests were carried out. In addition a three dimensional numerical model was established with the finite element code Abaqus to study local phenomena. The data from the fire tests were used to validate the model. Using the validated model, the investigated parameter set was extended. After finishing the calculations, recommendations for the design of the developed joints have been worked out.

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PREDICTION OF TEMPERATURES IN STEEL CONNECTIONS

Structural fire design is mostly based on single member tests. Due to the nature of these tests, the behaviour of the connections is neglected suggesting that they do not play a critical role in fire. In support of this theory, connections generally have a lower temperature than the surrounding structure during fires and are usually protected. This assumption of cooler connections is valid but this does not justify ignoring them in fire design. During both heating and cooling, connections will be subject to conditions, for example large moments and shear forces, which they will not typically have been designed for. The response of connections to these conditions is complex and is largely based on the material strength degradation and the interactions between the various components of the connection. To evaluate the material strength degradation over time and to predict how the behaviour of connections affects global performance in fire, temperature profiles must initially be established [1]. With the aim to quantify the temperatures within a joint, some studies with various temperature distributions have been done in several joints typologies [2].

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Methods for predicting connection temperatures

The Eurocode 3 suggests connection temperatures can be calculated as percentages of the mid-span beam flange temperature. However, results show this method to be unreliable and should therefore be used with caution.

The lumped capacitance method, based on the heated surface area of the connection and its volume –the local massivity value (A/V), showed good correlation with average connection temperatures. More work should be done to look at predicting temperatures of individual connection elements and to define what volume of the connection beams and columns should be included in calculations. The 3D finite element model, using the commercial software package Abaqus, showed good correlation with experimental results. This method uses heat transfer theory to predict connection temperatures over time and can be recommended if a detailed temperature profile is needed for mechanical analysis. A detailed yet simple method for predicting connection temperatures is still unavailable, and more work is required in this field.

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Temperatures of header plate connections during fire test on steel framed building at Mittal Steel Ostrava

To study the global structural and thermal behaviour of buildings in fire, a research project was conducted including a fullscale test on a three storey steel frame building at Mittal Steel Ostrava before demolition. The main goal of the experiment was to verify the method for predicting joint temperatures and to improve it for the cooling phase. Comparisons are made between the test results and the temperatures predicted by the structural Eurocodes.

Calculating the temperature of the beam-to-column/beam-to-beam connection from the measured gas temperature in the fire compartment based on the mass of the connection parts is overconservative/ conservative during the heating phase. A calculation based on the bottom flange temperature of the supported beam is less conservative/may be improved by using a factor of 1.0 instead of 0.88.

The sensitivity of the resistance of the bolts to the in predicted temperature was shown for different temperature predictions, and compared to the measured values. The next generation of analytical and numerical models for connection temperatures may lead to more economical design of connections exposed to elevated temperature and improved predictions during the cooling phase of the fire.

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Temperatures of connections partially encased in the concrete slab during the Mokrsko fire test

The Mokrsko fire test focused on the overall behaviour of the structure, which cannot be observed on the separate elements, and also on the temperature of connections with improved fire resistance. Measured values from the test show the differences between the behaviour of the element and the behaviour of the structure exposed to high temperatures during a fire.

The SAFIR program was selected to predict the temperatures in the connection, which was partially encased in the concrete slab. The fire was modelled using the Ozone 2.2 program. The results of the numerical simulations compared well with the measured temperature values in the connections. The maximum temperature of the lower bolt in the beam-to-column/beam-to-beam connection reached 56 %/46 % of the temperature in the lower flange in the beam midspan, and the upper encased bolt reached 17 %/22 % of the midspan maximum in the flange.

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Temperatures in unprotected joints between steel beams and CFT columns

The study presents experimental, numerical and analytical results of temperatures in different components of unprotected joints between steel beams and concrete-filled tubular columns in fire. The joint types include fin plate, endplate, reverse channel and T-stub. The results of the experiments indicate that the different components that are in the same region of a joint may be considered to have the same temperature. Steel to CFT column joint may be divided into two regions and an appropriate section factor may be calculated for each region to be used in lumped mass temperature calculation equation from EN 1993-1-2 for unprotected steelwork. Therefore, the main objective of this study is to derive suitable expressions to calculate the section factors for the different components of the joints tested in this study.

The experimental results have also been used to assess the simple temperature calculation method in Annex D of EN 1993-1-2, which relates the joint temperatures to the temperature of the connected beam. It has been found that this method generates grossly inaccurate results.

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NONLINEAR FINITE ELEMENT ANALYSIS OF RC STRUCTURES SUBJECTED TO FIRE

To define the fire resistance of structures as assemblies of structural elements, experimental investigations of models are almost impossible. The time dimension of spreading of the temperature field is practically impossible to be simulated on a model of small proportions. Hence, model investigations can hardly be accepted due to the high cost. For the last twenty years, particular importance has therefore been given to analytical definition of the problem.

The computer program FIRE have been developed as analytical tool to study the fire response of reinforced concrete frame structures. Histories of: displacements, internal forces and moments, stresses and strains in concrete and steel reinforcement, as well as current states of concrete (cracking and crashing) and steel reinforcement (yielding) are calculated subject to temperature field development in the thermal time history of the structure. Since a physical testing program for investigating the response of a large variety of structural elements under differing restraint, loading, and fire conditions is impractical and expensive, analytical studies supported by the results of physical experiments could efficiently provide the data needed to resolve questions related to the design of structures for fire safety. Parametric studies, helping to identify important design considerations, could be easily achieved throughout implementation of this program. The time response capability of FIRE can also be used to assess potential modes of failure more realistically and to define the residual capacity of structure after attack of fire.

The columns as structural elements have an important role in preventing loss of global stability of structures under fire. If these elements do not suffer failure, damages shall be of a local character, which shall enable evacuation and efficient extinguishing of the fire. For that reason the influence of different parameters as: element geometry; concrete cover thickness; type of aggregate; compression strength of concrete; steel ratio and intensity of the axial force and bending moment were analyzed and important conclusions for the fire resistance of centrically and eccentrically loaded RC columns exposed to fire from all sides, or incorporated in a wall for separating the fire compartment, were made. The results were presented by curves which enable determination of the fire resistance of these columns without use of numeric procedure. Four RC beams, exposed to different fire models were analyzed, and the predicted results were compared with those experimentally achieved by other researchers. As a next step the axial restrain effect on fire resistance of RC beams was analyzed.

Three-bay, two-storey reinforced concrete frame was analyzed too. For a given specific loading and element geometry and different fire scenarios, the fire resistance was defined.

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Residual concrete strength after fire action

Temperature over 400oC causes reduction of the compressive strength and other mechanical properties of concrete and this process is irreversible (the strength of concrete does not recover in the cooling phase). The mechanical properties of hot welded steel (reinforcing bars) decrease as well, but in the cooling phase they increase again. According to these statements and for realization of the repair projects of the fired RC structures, experimental and numerical determination of the residual concrete strength was done. Numerically achieved results with program FIRE correspond well with experimental results obtained by laboratory testing of specimens taken from the fired elements.

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Fire after earthquake

Calculating structural response to fire after earthquake is a few step process: modeling the structure including nonlinear analysis options; choice for earthquake analysis scenario; seismic nonlinear analysis: pushover or dynamic time history; fire hazards analysis to identify all possible fire scenarios; thermal analysis to calculate temperature history in each member; structural analysis to determine forces, stresses and deformations to estimate whether local or global collapse would occur during any of the fire hazard scenarios.

Using program FIRE, a two storey three bay RC frame was monotonically loaded with triangular distribution of storey horizontal forces (pushover from right to left) and then unloaded. After unloading the corresponding residual plastic displacement was defined. After unloading the structure was exposed to two different fire scenarios (in the first and the second story left bay) and the fire resistance of the frame was obtained.

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GLOBAL MODELLING OF THE BEHAVIOUR OF FRAMED BUILDINGS IN FIRE

Vulcan software

Experience increasingly shows that the interactions between components of large continuous framed buildings in fire are so complex that simplified analysis considering isolated elements is inadequate for reliable performance-based fire resistance design. On the other hand the use of general-purpose finite element software can lead to a very lengthy stage of model creation and development. The University of Sheffield has undergone a long-term process of development of the non-linear global modelling software *Vulcan*, with the objective of allowing researchers and designers to create and analyse thermo-structural models of buildings or three-dimensional subframes in different fire scenarios. A version of the program which includes a Windows interface has been used extensively in structural fire engineering design, mainly of steel/composite buildings. The software won two of the 2005 national software awards by the British Computer Society. Current development of the program is focused on enabling the analysis to continue up to ultimate collapse, so that the issue of robustness and progressive collapse in fire can be addressed properly.

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Static/Dynamic analysis for structural robustness modelling in fire

The loss of stability of structural elements in a fire can cause dynamic effects, including successive impacts or progressive collapse. Alternatively, unstable behaviour may be capable of regaining stability after either small or large deformations have occurred. A prime objective has been to provide Vulcan with the capability to perform dynamic analysis as well as quasi-static high-deflection, high-temperature modelling. This has already been applied to steel portal frames in fire, for which a UK design process based on rather arbitrary assumptions has been in existence for nearly 30 years; the new procedure has been used to develop a new simplified design approach to calculate final collapse temperatures. The development is intended to follow the structural behaviour from static response through local failure of components, and to model the subsequent dynamic behaviour using an explicit scheme. This kind of model is necessary in order to follow the sequence of behaviour leading to progressive collapse. It is currently being used to study the conditions under which an initial column failure may lead to a cascade of such failures or to re-stabilization. It will later be used to investigate building robustness when connections progressively fracture.

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Modelling localisation of tensile cracking of concrete slabs in fire

All of the software currently used to analyse the behaviour of large-scale floor systems in fire treats concrete as a homogeneous material, and treats cracking when the tensile peak strain is exceeded as being "smeared", both horizontally and through the layer system used in the slab model. This is practical but fallacious; concrete does not smear cracks in zones of high and largely uni-directional principal tensile strain in lightly reinforced slabs – it relieves the stresses which would be created by forming large localised cracks. High membrane tension above the protected beams, and at the interface between a slab and a core-wall, is caused by the combination of high angles of rotation with restraint to the differential edge movements which would be created in an isolated slab by high deflection in its central zone and low deflection at its protected edges. An advanced prototype XFEM slab element has been developed in which the occurrence and development of localised tensile cracking was modelled directly. This is now being followed-up with an attempt to develop a more generally applicable element to predict accurately the occurrence of this type of compartment integrity failure in global modelling.

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Component-based modelling for connection robustness in fire

The most promising way to enable the interaction of connections with beams, columns and slabs in fire is to use a component-based approach. This is especially important because of the high compressions and tensions, and the associated deformations, which coincide with moment, shear and rotation at different stages of a fire. This was recognised in about 2000, and a series of experimental and analytical projects since that time have been used to characterize components of common bolted connections under conditions of high temperature and high deformation. At present the objective is to create a general-purpose finite element to represent the column-face "connection" zone, later proceeding to the representation of the finite-length parts such as the column and beam-end shear panels which are included in the wider "joint" zone. The principles developed should be applicable to implementation in different software packages, but the element is being developed particularly for Vulcan.

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EXPERIMENTAL STUDIES OF STEEL CONNECTIONS IN FIRE

Since 1993 experimental studies have been conducted on common bolted steel and composite connections in fire. The early studies concerned rotational behaviour at elevated temperatures. More recent work has concerned the robustness of connections, especially their fracture when subjected to combinations of high rotation and high normal forces which usually change their direction as temperatures rise.

Moment-rotation-temperature characteristics of endplate connections

In two successive projects cruciform M- tests were performed at constant moment and increasing furnace temperature on flush and extended endplate connections, of which the first series were purely steel-to-steel. The later series included composite beams, and particularly connection details taken from the Cardington composite building frame.

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Testing of connections under combined moment, shear and tying forces

A large number of cantilevered connection tests to destruction on connections under inclined forces were performed at temperatures up to 650°C, on four typical steel beam-column connection types. Modelling using Finite Element analysis rationalised the results, which were subsequently used to help with the development of simplified component characteristics, to be used in constructing component-based joint elements for global modelling. The project's photos and test data can be downloaded from the website fire-research.group.shef.ac.uk/downloads.html. In a follow-on project similar tests are being performed on connections to concrete-filled and partially-encased composite columns in fire.

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Robustness in fire of connections to composite columns

The current project COMPFIRE, funded by RFCS, involves collaboration with groups at Coimbra, Luleå, Prague and Manchester, together with Tata Steel. It concerns the behaviour and robustness in fire of practical connections between steel or composite beams and two types of composite column - concrete-filled hollow sections and partially-encased H-sections. Among the institutions involved tests are being carried out at various scales, accompanied by detailed FE modelling, leading to the development of a component-based approach for these connections at elevated temperatures. During the first year of the project the Sheffield group is conducting a total of 20 tests under combined forces, in a setup similar to that used for steel-to-steel connections in the previous project, at both ambient and elevated temperatures. The types particularly addressed are end-plate connections to partially encased H-columns and reverse-channel connections to both square and circular concrete-filled hollow-section columns. These tests are to be used mainly to develop and validate connection component models which will enable connection interaction to be modelled in whole-structure modelling software. The objective is to create a general element to represent the column-face "connection" zone, possibly later proceeding to the representation of the finite-length zones such as the column and beam-end shear panels which are included in the wider "joint" zone. The principles developed should be applicable to implementation in different software packages.

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Test data is available from www.fire-research.group.shef.ac.uk/downloads.html. At present, access to the data sheets is restricted to authorised users, and is password-protected. If you wish to view or download them please contact Ian Burgess, ian.burgess@sheffield.ac.uk.

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THERMAL AND STRUCTURAL BEHAVIOUR OF CONCRETE SLABS AT HIGH TEMPERATURES

A new simplified fire-resistance design method for composite slabs, embodied in a recent design document, is based on a simplified model of the enhancement to yield-line slab capacity which is caused by tensile membrane action at high deflections. In fire such deflections are acceptable provided that no structural collapse or loss of fire compartmentation occurs. The method was investigated with respect to its own formulation, in comparison with numerical modelling, and using a large number of small-scale loaded ambient- and high-temperature tests. At model scale it was possible to perform large numbers of tests, and these were used to test both the simplified method and advanced modelling approaches. In particular, the membrane stresses and cracking mechanisms caused by thermal gradients through the slab thickness, acting alone, were studied. A detailed comparative study was made between the simplified method for tensile membrane action and modelling of a number of composite slabs using Vulcan. This highlighted particularly the structural failure case in which protected edge beams eventually fold, limiting the range within which tensile membrane action acts as the main load-bearing mechanism. A simple additional calculation which covers this structural resistance failure mode has been proposed.

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PERFORMANCE OF CELLULAR COMPOSITE FLOOR BEAMS UNDER FIRE CONDITIONS

Despite the current popularity of long-span composite flooring systems, the current structural fire engineering design codes EC3/4 Part 1.2 and BS5950 Part 8 do not contain rules or guidance on the fire resistance of composite floors employing cellular steel beams. The purpose of this project is to investigate the performance and failure mechanisms of composite cellular floor beams at elevated temperatures, including the influences of both flexure and shear. The research at the University of Sheffield is coordinated with a programme of physical model fire testing at Ulster University, which is providing carefully monitored data. A configurable finite element model has been developed to demonstrate the 3-dimensional behaviour of composite cellular beams, and this has been successfully validated against the tests, ensuring that all types of failure modes are predicted. Some progress has been made in developing a simplified global modelling technique for composite CBs, with the ultimate aim of permitting efficient whole-structure modelling. The project has also developed a design methodology for such members in fire.

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FIRE RESISTANCE OF COMPOSITE PARTIALLY FIRE PROTECTED FLOOR

The design of the floor steel to concrete composite slabs for fire resistance is traditionally based on prescriptive generic ratings that specify the minimum slab thicknesses and the required concrete cover to the reinforcing steel. Once large deflections occur, tensile membrane action can significantly increase the fire resistance of reinforced concrete slabs, especially two-way slabs. For ambient conditions, developed a theory to determine the load carrying capacity of reinforced concrete slabs at large deflections by considering the tensile membrane action. Park and Gamble and others, describe how significant tensile membrane action in slabs at ambient temperatures can occur if the movement of the edges of slabs is restrained. Both theoretical and experimental research into membrane action of concrete slabs at large displacements has been limited due to the difficulty in identifying any practical application. However, in an accidental design state, such as during a fire, large displacements of the structure are acceptable provided overall structural collapse is prevented. During 1995 and 2003, a total of seven fire tests were conducted on a full-scale, eight storey, steel framed building at Building Research Establishment Laboratory at Cardington. The test results show that the fire performance of steel-concrete composite floor is better than that obtained from traditional design method, and the load capacity of composite floor slab in fire condition is usually higher than the predicted capacity without considering membrane action.

Analytical unrestrained slab panel model

Following full-scale fire tests on a steel-framed building, together with observations from real fires, it has been shown that membrane action, at large displacements, of composite floors comprising steel deck, concrete, and anti-crack mesh, is extremely beneficial to the survival of the building. It was therefore decided to review previous research conducted on unrestrained concrete slabs, under large displacements, at normal temperatures. It was found that the assumptions used to develop previous theoretical predictions for the load-carrying capacity, for a given vertical displacement, are only valid for square slabs and do not conform to test observations for rectangular slabs. A theoretical approach is presented which is valid for both square and rectangular slabs and conforms to the mode of behaviour observed in tests. The design method is shown to give excellent correlation with published test data. A prediction for ultimate collapse of the slab due to fracture of the reinforcement is also presented, which limits the allowable mechanical strain in the reinforcement. Comparison with available test data shows that this prediction is always conservative. The design method has been validated, against the Cardington laboratory fire tests and a number of cold slab tests at large displacements. The method is, however, limited in that it forces the designer to use isotropic reinforcement which is acceptable for square concrete slabs but is uneconomical for rectangular slabs.

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Analytical zone model

An alternative method to calculate the load capacity of simply supported composite floor slabs with considering the membrane action is presented. The slab is divided into five parts at the limit state of load

capacity, including a centre-elliptic part and four rigid parts around. The deflection of the slab, the force of rebars in high temperature, and the force distribution between four rigid parts are reasonably assumed. According to force and moment equilibrium requirements on the slab, a series of equations are obtained to calculate the ultimate load capacity of floor slabs in fire condition. The effectiveness of this new method is validated through comparison with results from experiments and different theoretical simulations. The comparis on shows that this new method is more reasonable in predicting the deflection and ultimate load capacity of floor slabs in fire condition than previous methods.

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Advanced modelling of membrane action

Several studies have been published to the advanced modelling of the partially protected floor in Cardington frame as well as other tests. The results show that this type of modelling predicts the deflection behaviour with considerable accuracy, especially considering the uncertainties embodied in representing the biaxial properties of concrete at high temperatures, and using analysis which does not consider the formation of discrete cracks. All the cases modelled follow very much similar deflection patterns; even with boundary assumptions which neglect all edge support provided by the vertical wind-posts are relatively accurate away from the local vicinity of this edge. Accurate thermal modelling of the structure, particularly in this case by obtaining an accurate representation of the temperatures in the over-sprayed 1m zones at the outer ends of the primary beams, has a fault major effect compared with weakening of the slab at the location of the observed longitudinal crack, suggesting that the deflection pattern is more a function of temperature distribution than of structure loading and strength. The comparison between the modelling of basic cases and the test results shows very good correlation, indicating that such modelling is capable of being used to give a realistic picture of the structural behaviour of composite flooring systems in scenario-related performance-based design for the fire limit state. The advanced FE modelling of partially fire uprotected floors gives more freedom and economy in design Compaq to analytical models fixed to particular structural solutions.

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Design tool for membrane action in fire

Under the European RFCS project FRACOF was developed a technical document, design guide and design software based on Bailey's analytical simple design method. A review of existing relevant fire tests carried out in full scale buildings around the world is described and the corresponding test data are summarized as

well. Information is also included on observations of the behaviour of multi storey buildings in accidental fires. The document gives detailed explanation of the new large-scale fire tests of composite floor systems conducted under long duration ISO fire which provides more evidences about the validity of the simple design model. The conservativeness of the simple design model is also clearly illustrated through the comparison with the parametric numerical study conducted with help of advanced calculation models.

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FIRE RESEARCH AT THE LABORATORY OF STRUCTURAL ANALYSIS AND DESIGN, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF THESSALY

Numerical simulation of the behavior of steel and composite structures under fire conditions after earthquake events

Normally, the design of structures according to the current design codes is performed independently for the seismic and thermal actions. In particular, many theoretical and experimental studies have been published in the last 20 years about the seismic behaviour of structures. The scientific knowledge in this field has been incorporated in the recent seismic regulations in Europe and elsewhere. Moreover, considerable research effort has been devoted during the same period to the study of the behaviour of steel and composite structures at elevated temperatures. Recently, the research interest has been extended beyond the behaviour of materials and structural members at elevated temperatures, to the overall behaviour of real structures. To this end, large-scale experiments have been conducted at European level (e.g. the Cardington full-scale composite building fire tests). These studies have led to the identification of additional mechanisms through which the structures may resist the design loads at elevated temperatures. Much of this research has been consolidated in the latest versions of design rules against fire. The interest of the research team of the University of Thessaly is focused on the following:

Numerical analysis of the behaviour of structural elements at elevated temperatures

Detailed numerical models are developed in order to simulate the behaviour of steel and composite structural components (beams, columns and slabs), which are designed according to the guidelines of Eurocodes, under fire conditions. The sophisticated three-dimensional finite element models are submitted to coupled thermo-mechanical analysis. All the nonlinearities that are present in the physical models (dependence of the thermal and mechanical properties of the material on temperature, nonlinear material behavior, cracking etc) are considered.

The further work is to consolidate the behaviour of the structural members in order to express it through marcroscopicreaction-displacement functions having temperature as a parameter. These functions would be suitable for using them in analysis with frame elements, in order to evaluate the response of real structures. It is expected that these functions will present descending branches due to the reduction of the strength of the materials when the temperature increases.

Definition of the requirements for the combined action of fire after earthquake

Fire after earthquake scenarios are developed which are based to the performance-based design concept. The starting point of the work is the standard matrices of required performance of buildings against earthquake events which consider the structural performance, the non-structural performance and the earthquake intensity. The new parameter that will be introduced here is the required fire resistance. Fire resistance requirements may be different for the various earthquake intensity levels considered. The combination of the above parameters results to 3-dimensional matrices.

Fire design and analysis of model structures for the combined scenarios of fire after earthquake

The proposed "fire after earthquake" scenarios lead to different temperature-time records for the structural and the non-structural members. The main objective is to study model structures for various thermal scenarios considering also the damages in the structural members induced by the seismic events. The "consolidated" results of the coupled thermo-mechanical analysis are profitably used to analyse full-

size structures. Since the consequent numerical simulations will are relevant to single structural components or substructures, the detailed output of the detailed nonlinear finite element analysis are transformed into simplified analytical and numerical models useful for the analysis of more complex structural systems. The results of this procedure are the base for the evaluation of the limit resistance of the structures for this combined loading, the maximum fire resistance time and the nature of the failure.

Behaviour of composite slabs in elevated temperatures

The interest of the team of the University of Thessaly is also focused to the thermo-mechanical modelling of composite slabs with thin-walled steel sheeting in elevated temperatures.

The objective is to assess the thermal behavior of composite slabs through both simple and advanced calculation models and compare their results. More specifically, the results of the thermo-mechanical analysis, in terms of fire resistance, are compared with the expected fire resistance that results following the provisions of Eurocode 4, Part 1-2. Despite the significantly simplified procedure proposed by this norm, its application in the case of continuous composite slabs requires the involvement of a nonlinear iterative algorithm. The comparison is performed mainly in order to evaluate the effectiveness of simplified methods that are based on the proposals of Eurocode 4. Moreover the results of the thermal analysis which is conducted according to the principles of the heat transfer theory, applied through the finite element method, are compared with the temperature profiles for composite slabs proposed by Eurocode 4. Another objective is to study the fire performance of the steel-concrete slabs considering two structural systems: a simply supported and a continuous slab. The two systems are designed to have the same load bearing capacity at room temperature. Therefore, the objective is to evaluate the effect of static indeterminacy to the fire resistance of composite slabs.

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FIRE RESEARCH AT THE UNIVERSITY OF COIMBRA

The University of Coimbra, Faculty of Science and Technology (FCTUC) is a research and education organization located in central Portugal which was created in 1290. The Department of Civil Engineering is responsible for undergraduate teaching in Civil and Environmental Engineering and a large spectrum of postgraduate courses. It was established in 1972 and includes a staff of about 80 teaching academics covering structural engineering, hydraulics, geotechnics, construction materials and technology, urban planning, roads and transportation. The research unit ISISE (Institute for Sustainability for Innovation in Structural Engineering) is part of Structural Engineering. ISISE is organised in three research Groups: SMCT (Steel and Mixed Construction Technologies); HMS (Historical and Masonry Structures) and SC (Structural Concrete). Fire research is one of the research clusters of SMCT; the behaviour of steel and composite joints and the behaviour of restrained columns have been the main researches items of this cluster. SMCT comprises more than 50 people, including post-graduate students, plus a shared laboratory and modern equipment for mechanical testing and instrumentation.

Behaviour of beam-to-column steel joints under natural fire

Traditionally, beam-to-column joints are assumed to have sufficient fire resistance due to cooler temperatures and slower rate of heating, caused by the concentration of mass on the joint area. However, observation of real fires shows that on several occasions steel joints fail, particularly from their tensile components (such as bolts or end-plates) because of high strains induced by the distortional deformation of the connected members. This research work dealt with the following subjects: i) the characterisation of the behaviour of beam-to-column joints in fire, and ii) their influence on the overall behaviour of the structure subjected to a natural fire. Special emphasis was directed to the cooling phase, because it induces an unwanted failure mode: brittle failure of the tensile components. The experimental results from a full-scale building fire test and six beam-to-column sub-frames fire tests under a natural fire were studied based on their temperature development, structural deformability and failure modes. The analytical approach of this research involved the proposal and validation of a design methodology for steel joints under fire loading. The model is based on the Eurocode 3 approach and includes the representation of all components to allow the application of any combination of bending moment and axial forces that characterise a fire situation.

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Fire resistance of steel and composite steel-concrete columns in buildings

The purpose of this work was to study steel and composite steel-concrete columns in buildings, under fire situation. The influence of several parameters such as the contact with brick walls, the stiffness of the surrounding structure, the load level, and the slenderness of the columns, were the target of the parametric study carried out in the present research. Five sets of experimental tests, were performed. Results of the experimental tests were compared with numerical studies reproducing the conditions used in the tests, with the purpose of providing valuable data for the development or improvement of analytical designing methods. The main goal was to reproduce as much as possible, in the laboratory, the conditions to which the column is subject in a real building.

An experimental set-up was constructed in the Laboratory of Structures and Testing Materials of the University of Coimbra, to allow fire resistance tests on columns with restraint to thermal elongation. It was composed of a 3D-steel frame, allowing different positions of the columns, to provide different values of stiffness of the surrounding structure. Mechanical loads constant during the tests were applied by a hydraulic jack, controlled by a central unit. Thermal actions were applied by a gas-burned and an electrical furnace. The experimental programme was composed of the following:

- Steel H Columns embedded on walls (14 experimental tests);

- Bare Steel H columns with restrained thermal elongation (14 experimental tests);

- Composite steel-concrete partially encased H columns with restrained thermal elongation (12 experimental tests);

- Bare steel circular hollow section columns (8 experimental tests);

- Concrete filled circular hollow section columns (32 experimental tests).

The numerical modelling of the tests was performed with the finite element computer package ABAQUS. A geometrical and material non-linear analysis with imperfections was performed. A very accurate modelling of the experimental tests was done, with a very good agreement between experimental and numerical results, both in terms of temperatures, forces and deflected shapes of the columns.

For the steel H columns embedded on walls, the main conclusions of this research were that the contact with the wall provides the column a huge thermal gradient within the cross-section. The column under fire situation will behave as a beam-column, failing by bending provoked by thermal bowing, instead of behaving as a column, failing by buckling.

For the bare steel H columns, the main conclusion was that for realistic values of slenderness of the columns in a building, the detrimental effect of the axial restraint is cancelled by the beneficial effect of the rotational restraint. These two restraints seem to cancel each other, and the restraint to thermal elongation is not so important.

For the composite steel-concrete H columns, the major conclusions were the great increase of fire resistance provided by the concrete between flanges, compared with bare steel columns. No local buckling was observed in these columns, and failure by buckling occurred with detachment of the stirrups from the web.

For the concrete filled and bare steel circular hollow section columns, the major conclusions were that the load level, the cross-sectional dimensions, the slenderness ratio and the type of material used to fill the

column (i.e. concrete, reinforced concrete or fiber reinforced concrete) has significant influence in the fire resistance.

The major outcomes of this research work were proposals for the assessment of the temperature evolution within the cross-section of unevenly heated steel columns in contact with walls, as well as proposals for the calculation of the critical temperatures and fire resistance of steel bare columns.

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Robustness of open car parks under localised fire

This research work is part of the RFCS European ROBUSTFIRE project. A design philosophy aiming at the economical design of car parks exhibiting a sufficient robustness under localised fire is intended to be developed and practical design guidelines for the application of this design philosophy throughout Europe are expected to be derived. In other to reach this purpose, the work is divided into four main objectives: (i) A review of current practice and state of the art in the design and assessment of open car parks subject to localised fire and a state of the art on the behaviour of beam-to-column joints and steel columns in fire was performed; (ii) The required knowledge on the behavioural response of the individual frame structural elements directly affected by the localised fire and the resultant reduction of carrying capacity of the heated column should be acquired (by experimental tests and numerical simulations); (iii) Detailed numerical models as well as simplified analytical models of the fire response of critical structural components, including columns, connections and composite beams should be developed and validated; Finally (iv) a robustness assessment approach for steel composite car parks under fire, to be event-independent as far as possible should be developed and relevant and practical design guidance should be proposed.

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Composite joints for improved fire robustness

This research work is part of the RFCS European COMPFIRE project. The aim is to investigate and evaluate the behaviour of joints for improved fire robustness, particularly joints between beams and the most common composite columns (concrete-filled hollow sections). These composite columns are often assumed to possess inherently high fire resistance, yet there is very little knowledge on their joint behaviour in fire. The main outcomes of the work will consist in coherent performance-based design to steel and composite structures by focusing on the critical issue of the fire performance and robustness of joints. By developing practical methodologies for evaluating the full 3D behaviour of composite joints over the entire course of fire exposure, including the assessment of ductility limit, innovative fire engineering design solutions can be planned to avoid premature progressive collapse of a structure under fire attack.

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RESEARCH IN THE FIELD OF STRUCTURAL FIRE SAFETY ENGINEERING AT ETH ZURICH

Stability behavior of steel structures in fire

The structural resistance of steel members, in particular columns or beam-columns, under fire conditions is limited by three limit states and their interaction: First, full section yielding at elevated temperature (i.e. yield capacity) considering both axial compression-bending moment interaction and non-uniform temperature distributions (limit state 1); second, local and/or distortional buckling (limit state 2); and third, overall structural stability, especially flexural and lateral-torsional buckling (limit state 3). The reduction of steel strength during heating in fire as well as thermal gradients markedly affect the first limit state [1], while the reduced stiffness and the nonlinear stress-strain relationship of steel at elevated temperatures have a strong influence on the local buckling [2] – strongly affecting the cross-sectional capacity [3] – and overall buckling behaviour [4]. Several studies focusing on the flexural or lateral-torsional buckling resistance under fire conditions (for example [5], [6], [7], [8]) (limit state 3) implicitly consider section yielding (limit state 1). These studies assume that members without overall buckling effects, whose cross sections are classified as 'plastic' (Class 1), 'compact' (Class 2) or 'semi-compact' (Class 3), reach their full plastic or elastic capacity respectively without developing local buckling deflections even under fire conditions. However, elevated temperatures strongly influence the cross-sectional capacity and the local buckling behaviour of steel sections. Even cross-sections suitable for plastic design at ambient temperature may develop local buckling deflections in fire [2, 3], caused by large strains required to reach full section yielding due to the distinctly nonlinear stress-strain relationship of steel at elevated temperatures [9].

A comprehensive numerical parametric study (geometrically and temperature-dependent materially nonlinear analysis of the imperfect structure GTMNIA) using the finite element approach on the cross-sectional capacity of structural steel members in combined axial compression and biaxial bending under fire conditions has been carried out at ETH Zurich [3]. The cross-sectional capacity and local buckling behaviour of steel members in fire is strongly affected by the distinctly nonlinear stress-strain relationship of steel at elevated temperatures. The axial load has a marked effect on the cross-sectional capacity under fire conditions. Temperature-dependent normalized N-M interaction curves have been developed by means of the numerical results. These interaction curves for the cross-sectional capacity consider full section yielding (limit state 1) as well as local instability effects (limit state 2). A comparative study has shown that the simple adoption of the ambient temperature design rules in combination with temperature-dependent reduction factors for the yield strength reached at 2% strain does not lead to consistent results in many cases.

The interaction curves developed from the numerical results constitute an upper limit of the overall structural resistance considering member buckling effects (limit state 3). Comprehensive experimental and numerical studies on the flexural and lateral torsional buckling resistance of steel members as well as the local-global buckling interaction behaviour have been performed at ETH [4], [10], [11]. The experimental program comprised material tests at elevated temperatures as well as both cross-sectional capacity and slender column buckling furnace tests in concentric and eccentric compression at different temperatures and strain rates. The strain rate markedly influenced the stress-strain behaviour and the local and global buckling behaviour. A general analytical model for the slender column resistance has been developed. The model allows considering nonlinear stress-strain relationships, residual stresses, geometric imperfections and thermal creep effects.

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Fire safety of multi-storey timber buildings

In case of fire, combustible building materials like timber burn on their surface, release energy and thus contribute to the fire propagation and the development of smoke. The combustibility of wood is one of the main reasons why most building codes strictly limit the use of timber as a building material, in particular by limiting the number of storeys of timber buildings [12]. In Switzerland for example timber structures were mostly limited to low-rise buildings with 2 or less storeys, until 2005. Fire safety is the main precondition for the use of wood for multi-storey timber buildings and therefore an important criterion for the choice of material for buildings. Since the 90s, many research projects have focused on the fire behaviour of timber structures worldwide [for example 13, 14]. Some projects have been conducted by the Institute of Structural Engineering at ETH Zurich sponsored by the Swiss Agency for the Environment, Forests and Landscape (BAFU) and in collaboration with the Swiss Laboratories for Materials Testing and Research (EMPA) and different industrial partners (see Table 1). The research projects aimed at supplying basic data and information on the safe use of timber, in particular for multi-storey buildings. Further novel fire design concepts and models have been developed based on extensive theoretical studies, element and full scale testing as well as a large statistical data based on fires in buildings.

Research project	Testing type	Duration of fire tests
Fire resistance of timber-concrete composite slabs	Element tests under ISO-fire exposure	60 to 90 minutes
Fire resistance of timber slabs made of hollow core elements	Element tests under ISO-fire exposure	60 to 105 minutes
Fire resistance of light timber frame wall assemblies	Element tests under ISO-fire exposure	60 minutes
Fire resistance of timber block walls	Element tests under ISO-fire exposure	30 to 90 minutes
Fire resistance of multiple shear steel-to-timber connections	Element tests under ISO-fire exposure	30 to 70 minutes
Fire performance of wooden hotel modules	Full scale tests under natural fire conditions	4 minutes to burn-out

Table 1:   Overview of some recent research projects on the fire behaviour of timber structures conducted at the Institute of Structural Engineering of ETH Zurich

Design models of timber structures in fire usually take into account the loss in cross-section due to charring of wood and the temperature-dependent reduction of strength and stiffness of the uncharred residual cross-section. Based on extensive experimental analysis novel fire resistance models for load-carrying structures like timber-concrete composites slabs and timber slabs made of hollow core elements were developed [15, 16]. For timber frame wall and floor assemblies with void cavities only a little information is available. In particular no detailed charring model exists for the calculation of the charring depth after the fire exposed claddings have fallen off. As a result of a comprehensive research project on the fire behaviour of timber frame assemblies performed at the ETH Zurich, a charring model for timber frame assemblies with void cavities was developed based on an extensive FE-thermal analysis [17]. The FE-thermal analysis showed that the main physical reasons for the increased charring rate observed after failure of the claddings is that, at that time, the fire temperature is already at a high level while no protective char layer exists to reduce the effect of the temperature (i.e. heat transfer). Thus the more that the protective cladding delays the start of charring, the more the charring rate increases after failure of the protective cladding. The charring model takes into account the influence of high temperature after failure of the fire protective claddings as well as the heat flux superposition on the charring rate of the timber beams exposed to fire on 3 sides. The FE-thermal analysis was verified by fire tests on protected specimens exposed to one-dimensional charring.

The load-carrying capacity of timber structures is often limited by the resistance of the connections. Thus, highly efficient connections as multiple shear steel-to-timber connections with slotted-in steel plates and steel dowels are needed for an efficient design. The load-carrying capacity of multiple shear steel-to-timber dowelled connections with slotted-in steel plates in fire primarily depends on the temperature-dependent reduction of embedment strength of the timber members. In order to accurately predict the fire resistance of the connection, knowledge on the temperature distribution in the cross-section as well as the influence of steel elements (slotted-in steel plates and steel dowels) on the charring of the timber members is essential. Based on an extensive experimental and numerical analysis, a design model for the calculation of the load-carrying capacity in fire of multiple shear steel-to-timber dowelled connections with slotted-in steel plates subjected to tension was developed [18, 19]. The design model is in analogy with the "Reduced Cross-Section Method" according to EN 1995-1-2 commonly used for the fire design of timber members. The proposed design model takes into account different geometries of the connection and the influence of the steel elements on the temperature distribution in the cross-section.

In order to limit fire spread by providing adequate fire compartmentation, elements forming the boundaries of fire compartments are designed and constructed in such a way that they maintain their separating function during the required fire resistance time (insulation and integrity criteria). While fire tests are still widely used for the verification of the separating function of light timber frame assemblies, design models are becoming increasingly common. A comprehensive research project on the separating function of light timber frame wall and floor assemblies with cladding made of gypsum plasterboards and wood-based panels was carried out at ETH Zurich in collaboration with the EMPA. As result of the research project, a design method was developed based on physical submodels for each layer and the interaction between the layers forming the assembly [20]. Thus, the total fire resistance is taken as the sum of the contributions from the different layers (claddings, void or insulated cavities). The design method takes into account the influence of adjacent materials on the fire performance of each layer according to their function (protection and insulation values) and their interaction (position coefficients). The coefficients of the design method (basic protection and insulation values as well as position coefficients) were calculated by extensive finite element thermal simulations based on physical models for the heat transfer through separating multiple layered construction. The coefficients of the design method were then simplified by general equations. The material properties used for the finite element thermal simulations were calibrated and validated by fire tests performed on unloaded specimens at EMPA using ISO fire exposure. The design method was verified with full-scale fire tests, showing that the model is able to predict the fire resistance of timber assembly safely. The developed design method significantly extends the application range of the design method according to EN 1995-1-2 by giving additional data as well as physical models for the basic protection and insulation values as well as the position coefficients and permits the verification of the separating function of a large number of common timber assemblies.

The better knowledge in the area of fire design of timber structures from the research projects, combined with technical measures, especially sprinkler and smoke detection systems, as well as well trained and equipped fire brigade allow the safe use of timber and a wider field of application of timber for buildings. As a result the Swiss fire regulations of 2005 allow the use of timber structures in multi-storey medium-rise residential buildings up to 6 storeys. Many other European countries have also liberalized the use of timber for buildings or introduced fire regulations that permit the use of timber on the basis of performance.Text devoted to second subject prepared in length of about 10 lines.

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STRUCTURAL FIRE ENGINEERING RESEARCH AT THE UNIVERSITY OF MANCHESTER

Main areas of expertise:

- Post-flashover fire dynamics

- Heat transfer analysis

- Thermal and mechanical properties of construction materials at elevated temperatures

- Behaviour of steel, concrete and composite structures in fire

- Tensile membrane action

- Catenary action

- Behaviour of joints in fire

- Concrete filled tubular columns

- Behaviour of thin-walled steel structures

- Dissemination and education

Post-flashover fire dynamics

Work in this area includes assessment of rate of heat release in post-flashover compartment fires, assessment of accuracy of parametric fire curves in Eurocode, CFD simulation of post-flashover compartment fires, development of glass breakage model for compartment fire.

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Heat transfer analysis

The emphasis of research in this area is on development of analytical and design calculation methods to enable temperature distributions to be easily calculated in a number of common situations, including different components of steel beam/column connections with different methods of fire protection, connections to concrete filled tubular columns, concrete filled tubular columns, thin-walled steel structures.

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Thermal and mechanical properties of construction materials at elevated temperatures

Accurate prediction of structural fire resistance critically depends on supply of reliable input data of thermal and mechanical properties of materials, particularly at elevated temperatures. Work in this area include development of experimental, analytical and numerical procedures to quantify thermal conductivity, specific heat, stress-strain relationship of a number of construction materials, including intumescent coating, gypsum, foamed concrete and structural composites.

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Behaviour of steel, concrete and composite structures in fire

The University of Manchester researchers started research on structural behaviour in fire more than 20 years ago. This research covers all major aspects of structural behaviour in fire and ranges from structural members to whole structures. Research methodology includes experiments, numerical simulations, and the development of analytical and design methods. A large number of scientific papers have been published and only a selection is included in the reference.

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Tensile membrane action

Tensile membrane action is now a major load carrying mechanism to enable unprotected steelwork to be used. This mechanism was first researched in the 1960s. However, it was during the Cardington structural fire research programme that the potential of this load carrying mechanism was first identified. The University of Manchester researchers played the most important role in first identifying this load carrying mechanism and subsequently in conducting detailed research and development to enable this load carrying mechanism to be beneficially used by fire engineering practitioners.

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Catenary action

Catenary action describes the load carrying mechanism in a beam whereby the applied load on the beam is resisted by tensile action in the beam acting upon the deflection of the beam. Full development of catenary action has the potential to enable fire protection to be eliminated in steel beams. The Manchester researchers began work in this area some 10 years ago, covering numerical simulation and development of analytical methods. This topic has now emerged as the key in understanding structural robustness in fire. Related research includes joints in fire.

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Behaviour of joints in fire

Joint behaviour is one of the most important current topics of structural fire engineering research. The research goes beyond the traditional approach of quantifying connection moment-rotation-temperature relationships because there is significant presence of axial force in joints in fire. Joint behaviour has critical influence on structural robustness in fire. The Manchester researchers are engaged in research studies to develop methods of calculating temperatures in different joint components, joint component behaviour and effects of joints on structural behaviour. Research methods include fire tests, numerical simulations and development of analytical methods.

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Behaviour of thin-walled steel structures

Thin-walled structures have much more complicated modes of behaviour than normal steelwork. This is a relatively poorly understood area of structural fire engineering research, perhaps due to the use of thin-walled steel structures as secondary structural members. Work by the University of Manchester researchers includes single compression elements and panel construction.

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Dissemination and education

In addition to conducting extensive research on various topics of structural behaviour in fire, the Manchester researchers are also actively engaged in dissemination and education. A fire engineering undergraduate and postgraduate course has been taught at the University of Manchester since 1998. The one-stop shop www.structuralfiresafety.com represents a major initiative in web based dissemination of information in this area.

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FIRE RESEARCH AND DESIGN AT THE "POLITEHNICA" UNIVERSITY OF TIMISOARA, ROMANIA

The fire research at the Department of Steel Structures and Structural Mechanics of the "Politehnica" University of Timisoara is numerical and design oriented. The team is the drafter of the actual Romanian Regulation for Fire Design of Steel Structures (aligned to ENV 1993-1.2), was involved in the translation of the corresponding fire parts of EN1993-1- 2 and EN1994-1-2 and in the elaboration of the corresponding National Annexes, and also applied modern fire engineering in practice for design projects. Fire design of composite steel concrete structures Lately, there is a growing demand in Romania for steel structures, especially for industrial and commercial objectives, where erection speed is critical in the choice of the structural solution. The main problem of steel structures is their low fire resistance. Composite steelconcrete solutions have the advantage of increased resistance of the structural element, in the case of fire, as well as in normal conditions. One example of application of the advanced methods for composite steel- concrete buildings in Romania, using the SAFIR computer program, comprise the verification of the fire resistance of 150 minutes for the columns of a multi-storey steel-concrete building which is the tallest building in Bucharest, Romania (106 m). The columns are made by partially concrete encased section with crossed I hot rolled European profiles, in order to increase strength, rigidity and fire resistance. Another example is the verification of the fire resistance for the columns of a three-storey framed building structure for the LINDAB-Romania Company Headquarters, in Bucharest. Taking into account the specific of LINDAB – Romania (systems of steel industrial buildings) the special demand was that the resistance structure must be visible steel, made by circular columns. Because for this type of building, according to Romanian fire regulations, the columns must have 120 minutes of fire resistance, the solution of reinforced concrete filled CHS columns was chosen.

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Fire after earthquake

Fire following earthquake can cause substantially loss of life and property, added to the destruction already caused by the earthquake, and represents an important threat in seismic regions. On the other hand, even when no fire develops immediately after an earthquake, the possibility of later fires affecting the structure must be adequately taken into account, since the earthquake induced damages make the structure more vulnerable to fire effects than the undamaged one. The numerical research developed at the "Politehnica" University of Timisoara evaluates the fire resistance time for unprotected steel moment resisting frames, in the hypothesis that they are already damaged by the earthquake, using advanced methods for earthquake and subsequent fire analysis, and using both standard and natural fire scenarios. The natural fire scenarios consider the situation before earthquake, for which all active fire fighting measures are available, and the situation after an earthquake, for which all or part of the fire fighting measures are no more available and the fire load density is consequently modified. Moderate and severe seismic actions are used for designing the steel structures. The influence of the damage level induced by the earthquake on the fire resistance is emphasized.

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Numerical modelling of membrane action of composite slabs in fire situation

Membrane action in fire is now an intensively researched area, for which more improvement is always necessary. The numerical research, in collaboration with the University of Liege, Belgium, was done with the SAFIR program, in order to derive more simple models for representing the partially protected composite floors in fire situation. The numerical models are calibrated using the results of three full scale tests that have been performed in recent years. A complete and detailed numerical modelling of the membrane effect is quite complex and CPU time consuming, due to the simultaneous presence of beams and of orthotropic shells. If such a numerical simulation can be done in research centres and universities, it is not practically applicable for real projects that have to be analyzed in shorter time. The first objective of the research was to derive more simple models for representing the partially protected composite floors in fire situation that, on the price of simplifications and approximations, would nevertheless yield a sufficiently close to reality representation of the structural behaviour and a safe estimate of the load bearing capacity. The second objective was to highlight the influence of some critical parameters on the behaviour and fire resistance of composite slabs such as the amount of reinforcing steel in the slab, the thickness of the slab, the load level and the flexibility of the protected edge beams.

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FIRE RESEARCH IN POLAND

The main purpose of this state-of-the-art report is to present and summarize the actual knowledge about who is who in the field of fire research and fire engineering in Poland.

General division

The fire engineering activity sector in Poland can be divided in several groups of participants, out of which four main groups can be distinguished, i.e. state institutions, universities & academia, research units and others (mainly private sector, consortia of Polish private or public partners, PPP, etc.).

State Institutions

The leading role is played by the National Headquarters of State Fire Service (KG PSP) and its units which are mainly focused on the fire prevention with related directions and regulations aimed at increasing the global safety level of buildings, their users and rescue teams. It participates in conducting many research projects, majority of which are financially supported by the Ministry of Science and Higher Education, but some of them are managed within national or international consortia and using European funds as well. More detailed information about the activity of the National Headquarters of State Fire Service and examples of projects currently being done can be found on http://www.straz.gov.pl/.

Universities and Academia

Amongst the large number of Polish technical universities one can recognize 6 universities which seem to be the most active players in this group. One of them is the Main School of Fire Service (SGSP) in Warsaw, http://www.sgsp.edu.pl/, which as a university is partly subordinate to the Ministry of Science and Higher Education but also is dependent on the Ministry of Interior and Administration as the separate organisational unit of the national State Fire Service (PSP). This is the only one such organization in Poland and one out of the few state technical universities in the world which trains the fire service officers, educates civilian specialists in the fire safety and civil safety engineers at the same time. The laboratories of the Main School of Fire Service are pretty well equipped with stands for evaluation of strength parameters of constructional materials in fire conditions. One of the currently conducted research projects is oriented to the impact of heating rate on parameters of structural steel under fire conditions, which seems to play the crucial role for correct assessment of load-carrying capacity of structural members subjected to elevated temperatures and as the input data in case of advanced numerical analyses of structural systems.

The next significant representative amongst universities is the Cracow University of Technology, http//www.pk.edu.pl/. The university is represented in our COST action by Dr Mariusz Maślak, who is the member of WG1. The main topics of research currently conducted in the university concentrate mainly on safety problems of concrete structures and some reliability aspects of structures subject to fire conditions.

The next one is the oldest technical university in Poland, the Warsaw University of Technology with its Faculty of Civil Engineering, http://www.pw.edu.pl/. The university is widely represented in our action by Dr Lesław Kwaśniewski, and Dr Paweł A. Król, who are the members of WG2 and Dr Robert Kowalski – member of WG3. Our main scientific interests are dedicated to different aspects of load-carrying capacity of concrete and steel structures as well as virtual testing and computer modelling of structures in fire conditions.

The last on the list of universities is the University of Warmia and Mazury in Olsztyn, http://www.uwm.edu.pl/. The University of Warmia and Mazury is relatively very young unit as it was founded on the 1 September, 1999 after merging three educational institutions. The University of Warmia

and Mazury is represented in our COST action by Dr Zenon Drabowicz, member of WG3, whose scientific interests concentrate on the evaluation of the capacity of structures after fire and approximate models for analysis of structures under fire loading. Dr Drabowicz cooperates with Prof. Wojciech Skowroński, currently employed in the Wroclaw University of Environmental and Life Sciences, Institute of Building, http://www.up.wroc.pl/, who has been the author of the first Polish monograph on fire safety issued in English.

It's also a good opportunity to mention another individual personality - Prof. Dariusz Gawin, of the Łódź University of Technology, Faculty of Building, Architecture and Environmental Engineering, http://www.p.lodz.pl/, who is a distinctive specialist on modelling thermo-hydro-mechanical coupling phenomena in concrete and other porous building materials.

Research Units

The last part of this report is dedicated to research units and scientific centres from among which the distinctive position belongs to the Building Research Institute (ITB) in Warsaw, http://www.itb.pl/. Since 1 May, 2004 the Building Research Institute has become the Notified Body to the European Commission and to the other member states of EU designated for the task concerning the assessment of building products conformity, according to the requirements of European Directive. The Department of Fire Research which is the separate unit of the Building Research Institute has about 40 years of experience in the field of fire research. The Fire Research Department consists of the Division of Fire Resistance and Smoke Control and the Division of Fire Development and Material Testing. With the Fire Research Department works jointly the Certified Fire Testing Laboratory, formally the separate unit within the structure of the Building Research Institute. The Fire Testing Laboratory is equipped with stands and furnaces allowing for fire tests on separated structural members, floor and wall structural systems, building products, etc. The other notified body, but working under supervision of the National Headquarters of State Fire Service and the Ministry of Interior and Administration is the Fire Protection Research Centre – State Research Institute (CNBOP) in Józefów, Mazovia province, http://www.cnbop.pl/. The Centre has authorization of ministry and notification of European Commission in scope of Directive 89/106/EEC "Construction Products" as well as Directive 89/686/EEC "Personal Protective Equipment". Moreover, the Fire Protection Research Centre takes actively part in elaboration and revising standards and other standardization documents in the scope of: Personal Protective Equipment Technical Committee No. 21, Floor Coverings and Textile Materials Combustibility Technical Committee No. 27, Fire Safety of Buildings Technical Committee No. 180, Rescue and Extinguishing Equipment Technical Committee No. 244 and Fire Alarm Systems Technical Committee No. 264. The Fire Protection Research Centre is represented in our action by Mr Krzysztof Biskup, who is the member of WG1.

Others

There is no technical possibility to mention all the projects being currently conducted within the private sector for research and development, but there are at least several examples that could be presented and discussed. One of them is the project concerning development of complete building system based on perlite and vermiculite aggregate, allowing for thermal insulation of structural members, passive fire protection of existing structures and erecting new low residential buildings.

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RECENT FIRE SAFETY RESEARCH AT THE CHAIR FOR METAL STRUCTURES, TECHNISCHE UNIVERSITÄT MÜNCHEN

Utilisation of Membrane action for Fire Design of Composite-Beam-Slab-Systems

The use of membrane action for the design of composite-beam-slab-systems in fire can reduce the costs of fire protection measures considerably. For most of the secondary beams no fire protection is necessary. Several research projects in the last years were run to investigate this issue. But there are still questions remaining. E.g. it has to be clarified if the edge beams between two slab panels can be designed like a composite beam or if only the steel beam can be taken into account. The reason is that huge cracks appear at the edge beams due to large rotations of the concrete slab. Therefore it is not sure that the shear studs can transfer the shear forces over the cracks.

A research programme (IGF 16142 N) in cooperation between the Technische Universität München and the Leibniz Universität Hannover recently started to clarify the remaining issues and enable the use of membrane action in Germany. The project is mainly sponsored by the German Bundesministerium für Wirtschaft und Technologie and many industry partners. The research project includes two large scale fire tests which were performed in 2010 near Munich.

Intumescent Coating Systems on Steel Columns in Interaction with Industry Claddings

Intumescent coating systems are indeed a good method to protect steel members in case of fire. The disadvantage of these paints is that nobody can predict the behaviour of joints, crossings or partly protected areas. This is the reason why the Technische Universität München wants to explore these important subjects.

The research project "Intumescent coating systems on steel columns in interaction with industry claddings" contributes to answer various questions. This project is about three H-profiles (usually used as steel columns) on one side planked with a usually used steel cassette-cladding and on the three other sides painted with intumescent coating. Thermocouples fixed by point welding were mounted to sev-eral points on and in the steel columns and on the metal facade – profiles. The test was run with the ISO fire curve.

Simultaneous with the fire tests numerical simulations were realized. The comparison of the measured and the computed results is quite good. The implementation of the exact processes during the impact of fire in the intumescent layer must be approved.

Patch Loading under Fire Conditions

This research deals with the local buckling of steel plates subjected to patch loading at elevated temperatures. In case of fire, both yield stresses and elasticity modulus fall depending on the steel temperature. Thus higher limited strains (2% instead of 0.2%) are permitted by construction design. The lateral buckling of the web of girders under patch loading is also influenced by the fire.

The practicable approach to the above described phenomenon is the yield line theory which is ex-tended with the consideration of the higher deformations. Our task is to take out the description of the stability problem of the girders webs under patch loading and fire. Available approaches could be used and then usefully developed. The theoretical investigations would be substantiated with finite element simulations.

Kamil Vargovský, kamil.vargovsky@gmail.com

PRACTICAL ACTIVITY OF FIRE ENGINEERING AROUND PROBLEMATIC OF EUROCODES IN SLOVAK REPUBLIC.

Official standpoint Ministry of interior Slovak Republic for Fire resistance of building structures in the Slovak republic under Eurocodes:

Fire resistance of building structures in accordance with § 8 promulgation MV SR no. 94/2004 statute is determined:

- on the basis of initial type testing (act no. 90/1998 statute about building products as amended),

- by calculation according to technical standards (in cases where it is possible to express all the relevant factors by calculation , for example under the so-called „Eurocodes for the design of constructions to the effects of fire "),

- by test and calculation (in those cases where the examination is not possible to express and show all the relevant factors affecting the fire resistance test of building construction).

The decisive factors:

- all the important building-physical properties, thermal and mechanical parameters depending on the temperature, at which the known dimensions and for the construction element (structure) allow to simplify the determination of fire resistance.

Reviewed building construction is designed to:

- effects of mechanical loading at normal temperature ambient according to Eurocodes,

- the various factors in the tables for each building elements,

- the temperature curve,

- to determine the fire resistance of structural element.

Theoretical – experimental estimation of the supporting external wall fire resistance of the wood constructional system Φ- HA STANDARD

Expertise was elaborated for the supposed fire resistance of the construction:

- Wall: REI 45 (o → i) – by the effort of the wall by the fire from the outside according to the STN EN 1363 - 2;

- Wall: REW 45 (i → o) – as fire closed area by the fire exposition from the inside according to the STN EN 1363 – 1.

Expertise was elaborated:

- According to terminal condition of the fire resistance R, E, I, W;

- With the application of the theoretical calculation according to the line STN EN 1995-1-2:2004 – R, E;

- With the application of theoretical calculation of thermal field (Fourier partial differential equation of the non stationary heating conduction) I.

It was proved that: wooden supporting circumferential wall of the constructional system Φ- HA STANDARD by the fire exposition from the outside according to the STN EN 1363-2 suits to the fire resistance REI 45 (o

→i) and by the fire exposition from the inside according to the STN EN 1363-1 suits to the fire resistance REW 45 (i →o).

Theoretical – experimental estimation of the constructional system fire grading (REW 60) for the steel arc halls.

Expertise was elaborated for the supposed fire resistance of the construction:

- REW 60 (i → o) – as fire closed area by the fire exposition from the inside according to the STN EN 1363-1.

- Expertise was elaborated:

- according to the terminal conditions of the fire resistance R, E, W;

- with the application of the theoretical calculation according to the line STN EN 1995-1-2:2004;

- with the application of theoretical calculation of thermal field (Fourier partial differential equation of the no stationary heating conduction)W, I.;

- with the application of the simulation of the virtual model of the building construction joined with static and thermal analysis.

It was proved that: frameless steel constructional system for the arched halls HUPRO by the fire exposition from the inside according to the STN EN 1363-1 suits to the fire resistance REW 60 (i →o).

Estimation of equivalent fire time period duration of family house - model of fire according STN EN 1991-1-2. Combination of 1-zone model and 2-zone model.

Results:

Maximal temperature in fire area - 1284 °C, at 74. minute. Minimal temperature in fire area - 195,37 °C at 130. minute. Maximal rate of heat release in fire area - 13,50 MW at 18,4. minute. Zones interface elevation h = 1,85 m at 2,00. minute.

Next subsidiary results:

temperature of cold zone - 21 °C at 2,00. minute;

pyrolysis rate - 0,84 kg/s at 18,4. minute and next duration to 75,2. minute, total duration of fire - 130 minute;

expansion of fire area 54,00 m2 at 14,00. minute;

oxygen mass of fire are - minimum mass 1,09 kg at 73,00. minute.

References:

Announcement of the Ministry of Interior of the Slovak Republic N. 94/2004 Z. z. - Technical requirements for the fire safety by building and using the buildings

Announcement of the Ministry of Interior of the Slovak republic N. 121/2002 Z. z. - About fire prevention

STN 92 0201-2 Fire safety of buildings. Common provisions. Part 2.: Building construction

STN EN 13501-2 Fire classification of construction products and building

elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services

STN EN 1363-1 Fire resistance tests - Part 1. General requirements Requirements of fire grading the external wall

STN EN 1363-2 Fire resistance tests – Part 2: Alternative and additional procedures

STN EN 1365-1 Fire resistance tests for load bearing elements– Part 1: Walls

STN EN 1990 Eurocode: Principles of construction projection (E)(including Attachment A1: Buildings (S))

STN EN 1991 – 1 – 2 Eurocode 1: Constructions loading –part 1-2: general loading – construction loading strained by the fire

STN EN 1993 – 1 – 2 Eurocode 3: Design of steel structures - Part 1-2: General rules - Structural fire design

STN EN 1995 – 1 – 2 Eurocode 5: Wooden construction design. Part 1-2: General rules. Construction design for the influence of fire loading

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Ed.: Wald F., Šulcová Z.: (K výpočtu požární odolnosti nosných konstrukcí) To the calculation of fire resistance of supporting constructions, ČVUT Praha 1/2008. ISBN 978_80-01-03943-4

F. Wald a kol.: Príručka k STN EN 1990, Zásady navrhovania konštrukcií (The calculation of the fire resistance building constructions), ČVUT Praha 2/2005. ISBN 80-01-03157-8

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Danica Kačíková a kol.: Materiály v protipožiarnej ochrane (Materials in fire protection), TU Zvolen 2007. ISBN 978-80-228-1725-7

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Technical and drawing documentation from submitte

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FIRE RESEARCH AT THE UNIVERSITY OF COIMBRA

The University of Coimbra, Faculty of Science and Technology (FCTUC) is a research and education organization located in central Portugal which was created in 1290. The Department of Civil Engineering is responsible for undergraduate teaching in Civil and Environmental Engineering and a large spectrum of postgraduate courses. It was established in 1972 and includes a staff of about 80 teaching academics covering structural engineering, hydraulics, geotechnics, construction materials and technology, urban planning, roads and transportation. The research unit ISISE (Institute for Sustainability for Innovation in Structural Engineering) is part of Structural Engineering. ISISE is organised in three research Groups: SMCT (Steel and Mixed Construction Technologies); HMS (Historical and Masonry Structures) and SC (Structural Concrete). Fire research is one of the research clusters of SMCT; the behaviour of steel and composite joints and the behaviour of restrained columns have been the main researches items of this cluster. SMCT comprises more than 50 people, including post-graduate students, plus a shared laboratory and modern equipment for mechanical testing and instrumentation.

Behaviour of beam-to-column steel joints under natural fire

Traditionally, beam-to-column joints are assumed to have sufficient fire resistance due to cooler temperatures and slower rate of heating, caused by the concentration of mass on the joint area. However, observation of real fires shows that on several occasions steel joints fail, particularly from their tensile components (such as bolts or end-plates) because of high strains induced by the distortional deformation of the connected members. This research work dealt with the following subjects: i) the characterisation of the behaviour of beam-to-column joints in fire, and ii) their influence on the overall behaviour of the structure subjected to a natural fire. Special emphasis was directed to the cooling phase, because it induces an unwanted failure mode: brittle failure of the tensile components. The experimental results from a fullscale building fire test and six beam-to-column sub-frames fire tests under a natural fire were studied based on their temperature development, structural deformability and failure modes. The analytical approach of this research involved the proposal and validation of a design methodology for steel joints under fire loading. The model is based on the Eurocode 3 approach and includes the representation of all components to allow the application of any combination of bending moment and axial forces that characterise a fire situation.

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Santiago, A., Simões da Silva, L. and Vila Real, P., (2010) "Numerical modelling of the influence of joint typologies on the 3D behaviour of a steel frame under a natural fire", Fire Technology, 46, pp.49-65, doi: 10.1007/s10694-009-0099-3.

Fire resistance of steel and composite steel-concrete columns in buildings

The purpose of this work was to study steel and composite steel-concrete columns in buildings, under fire situation. The influence of several parameters such as the contact with brick walls, the stiffness of the surrounding structure, the load level, and the slenderness of the columns, were the target of the parametric study carried out in the present research. Five sets of experimental tests, were performed. Results of the experimental tests were compared with numerical studies reproducing the conditions used in the tests, with the purpose of providing valuable data for the development or improvement of analytical designing methods. The main goal was to reproduce as much as possible, in the laboratory, the conditions to which the column is subject in a real building. An experimental set-up was constructed in the Laboratory of Structures and Testing Materials of the University of Coimbra, to allow fire resistance tests on columns with restraint to thermal elongation. It was composed of a 3D-steel frame, allowing different positions of the columns, to provide different values of stiffness of the surrounding structure. Mechanical loads constant during the tests were applied by a hydraulic jack, controlled by a central unit. Thermal actions were applied by a gas-burned and an electrical furnace. The experimental programme was composed of the following:

- Steel H Columns embedded on walls (14 experimental tests);

- Bare Steel H columns with restrained thermal elongation (14 experimental tests);

- Composite steel-concrete partially encased H columns with restrained thermal elongation (12 experimental tests);

- Bare steel circular hollow section columns (8 experimental tests);

- Concrete filled circular hollow section columns (32 experimental tests).

The numerical modelling of the tests was performed with the finite element computer package ABAQUS. A geometrical and material non-linear analysis with imperfections was performed. A very accurate modelling of the experimental tests was done, with a very good agreement between experimental and numerical results, both in terms of temperatures, forces and deflected shapes of the columns. For the steel H columns embedded on walls, the main conclusions of this research were that the contact with the wall provides the column a huge thermal gradient within the cross-section. The column under fire situation will behave as a beam-column, failing by bending provoked by thermal bowing, instead of behaving as a column, failing by buckling.

For the bare steel H columns, the main conclusion was that for realistic values of slenderness of the columns in a building, the detrimental effect of the axial restraint is cancelled by the beneficial effect of the rotational restraint. These two restraints seem to cancel each other, and the restraint to thermal elongation is not so important.

For the composite steel-concrete H columns, the major conclusions were the great increase of fire resistance provided by the concrete between flanges, compared with bare steel columns. No local buckling was observed in these columns, and failure by buckling occurred with detachment of the stirrups from the web.

For the concrete filled and bare steel circular hollow section columns, the major conclusions were that the load level, the cross-sectional dimensions, the slenderness ratio and the type of material used to fill the column (i.e. concrete, reinforced concrete or fiber reinforced concrete) has significant influence in the fire resistance.

The major outcomes of this research work were proposals for the assessment of the temperature evolution within the cross-section of unevenly heated steel columns in contact with walls, as well as proposals for the calculation of the critical temperatures and fire resistance of steel bare columns.

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Rodrigues J.P.C., Neves I.C., Valente J.C. (2000), Experimental research on the critical temperature of compressed steel elements with restrained thermal elongation, Fire Safety Journal, 35, 77-98;

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Pires T.A.C., Rodrigues J. P. C., Rêgo Silva J.J., (2010), Buckling of Concrete Filled Steel Hollow Columns in case of Fire, Stability and Ductility of Steel Structures SDSS´Rio2010.

Robustness of open car parks under localised fire

This research work is part of the RFCS European ROBUSTFIRE project. A design philosophy aiming at the economical design of car parks exhibiting a sufficient robustness under localised fire is intended to be developed and practical design guidelines for the application of this design philosophy throughout Europe are expected to be derived. In other to reach this purpose, the work is divided into four main objectives: (i) A review of current practice and state of the art in the design and assessment of open car parks subject to localised fire and a state of the art on the behaviour of beam-to-column joints and steel columns in fire was performed; (ii) The required knowledge on the behavioural response of the individual frame structural elements directly affected by the localised fire and the resultant reduction of carrying capacity of the heated column should be acquired (by experimental tests and numerical simulations); (iii) Detailed numerical models as well as simplified analytical models of the fire response of critical structural components, including columns, connections and composite beams should be developed and validated; Finally (iv) a robustness assessment approach for steel composite car parks under fire, to be event independent as far as possible should be developed and relevant and practical design guidance should beproposed.

References:

A. Santiago, C. Haremza, L. Simões da Silva and J.P. Rodrigues, "Numerical Behaviour of Steel Columns subject to Localized Fire Loading", Civil-Comp Press, 2009, Proceedings of the Twelfth International Conference on Civil, Structural and Environmental Engineering Computing, B.H.V. Topping, L.F. Costa Neves and R.C. Barros, (Editors);

Haremza, C., Santiago, A., Simões da Silva, L. and Rodrigues, J.P.C., "Numerical analysis of composite steelconcrete car parks subjected to localized fires", in Luís Simões da Silva, J. Almeida Fernandes,

António Baptista, Elsa Caetano, Paulo Piloto, (eds.), Construção Metálica e Mista VII, pp II-397-406, cmm Press, Lisbon (2009).

Composite joints for improved fire robustness

This research work is part of the RFCS European COMPFIRE project. The aim is to investigate and evaluate the behaviour of joints for improved fire robustness, particularly joints between beams and the most common composite columns (concrete-filled hollow sections). These composite columns are often assumed to possess inherently high fire resistance, yet there is very little knowledge on their joint behaviour in fire. The main outcomes of the work will consist in coherent performance-based design to steel and composite structures by focusing on the critical issue of the fire performance and robustness of joints. By developing practical methodologies for evaluating the full 3D behaviour of composite joints over the entire course of fire exposure, including the assessment of ductility limit, innovative fire engineering design solutions can be planned to avoid premature progressive collapse of a structure under fire attack.

References:

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WG3

Integrated Design

Chairman Paulo VILA REAL, Portugal, pvreal@ua.pt

Co-chairman Jyri OUTINEN, Finland, jyri.outinen@ruukki.com

WG3 INTRODUCTION

On the framework of WG3 – Integrated Design, several questions were prepared to find out which are the current design practice in the member countries regarding fire safety in buildings. Thirteen countries have responded to the call: Belgium, Czech Republic, Finland, France, Germany, Greece, Hungary, Italy, Poland, Portugal, Slovakia, Spain, and United Kingdom.

Questions about building regulations, design codes approvals process, insurance companies, qualification requirements for designers, precedence of performance-based fire engineering projects and passive fire protection have been made.

The aim is to provide information to participants about the practice in other countries. Building and design to other countries meet often a variety of problems because of different procedure and acceptance. To help in this and also in co-operation between researchers from different countries this questionnaire has been gathered. Although EU should make this kind of interaction easier, the national regulations vary a lot and therefore this kind of information is valuable.

All the answers have been collected and put together in this document so that a comparison could be made between them. The way in which designers, regulators and authorities currently deal with the issues of fire safety in buildings in the WG3 member countries, can be checked hereafter.

The following questions, mostly suggested by Dr. Florian Block, have been sent to the members, together with comments (*in italics*) on the returned information:

1. Building Regulations

1.1   Are the Building Regulation Prescriptive / performance-based (i.e. is it possible to design from first principles using finite element analysis, CFD, etc to show that the intents of the Building Regulations are met?)

Most of the countries allow for performance-based design and the use of advanced calculation methods. Only in Greece, Hungary and Slovakia the regulations are purely prescriptive and do not allow for the use of advanced calculation methods.

1.2   What are the Building Regulations relevant for fire called and who is the issuing body?

Each country provided a list of their Building Regulation for Fire Safety.

1.3   Is there additional guidance available to interpret the Building Regulations for fire?

Some Countries have guides and FAQ's. France, Greece and Italy do not have this type of information from the authorities.

1.4   Are there different regulations for certain types of buildings (I.e. schools, hospitals, airports, railway stations)?

In all the Countries the regulation covers the most type of buildings

2. Design Codes

2.1   What are the relevant national or international/European standards required to undertake the design of:

- Means of escape

- Smoke management

- Fire resistance of the construction

Fire fighting

Fire safety systems (alarm, suppression, …)

Most of the Countries do not have relevant regulation for Means of escape, Smoke management, Fire fighting and Fire safety systems (alarm, suppression, …), but some guidance are given in the National Regulation for fire safety or some rules are used from NFPA. Only Poland has referred the EN 12101 - Smoke and heat control systems, which also should be used in the other European Countries. All the countries have adopted the structural Eurocodes for checking fire resistance of constructions.

2. 2   Is it possible to use Eurocodes or other international fire standards in lieu of the local code?

All the countries have adopted the structural Eurocodes.

2.3   Are there available the translations of the fire parts of Eurocodes? Which ones?

For the time being only Greece, Hungary and Italy do not have any translation available.

2.4   Are the national annexes available in internet

Only Finland, Greece and UK provide the National Annexes in the internet.

3. Approvals process

3.1   What is the normal route to get a project approved?

- Via a public body

- Via a private body

- Self-certified

The projects are approved in most of the Countries via a public body.

3.2   What is the position of the fire brigade in the process?

In all the Countries the fire brigade plays an important role in the approval process.

3.3   Is there a third party review process common?

In all the Countries it is not common to have a third party review process.

3.4   Is it necessary to follow an alternative route of approvals for performance-based design and what would that route be?

For the Countries where it is possible to use performance-based design the project follows the same route as for prescriptive approach, i.e. the authorities must approve the project.

3.5   What is the normal time frame for the approvals process?

Not easy to define. The time depends on the complexity of the project.

3.6   What level of information must be provided to the approving body?

In all the Countries the normal details of a project of fire safety of buildings.

3.7   Are any specific facilitators required to help the engineer in the approvals process?

In most of the countries there are no specific facilitators required to help the engineer in the approvals process, but in Czech Republic, Greece, Hungary, Portugal and Spain the support can be asked to the authorities.

4. Insurance companies

4.1   Are insurance companies involved in the design process?

In most of the countries no, but in Spain requirements of insurance companies are more restrictive that authorities for important projects, for instance; skyscrapers or industrial installations.

4.2   Are insurance companies open to a discussion on fire safety?

In most of the countries insurance companies are not particularly concerned with this matter when establishing insurance premium, they are normally conservatives. Only in Belgium and Finland the insurance companies open to a discussion on fire safety.

5. Qualification requirements for designers

5.1   Is it required to hold specific certificates/licenses in the member state to undertake fire safety design and fire engineering?

In some Countries no (Belgium, France, Germany in some federal sates, Greece, Spain and UK) and in other yes (Czech Republic, Finland, Germany in some federal sates, Hungary, Italy, Poland, Portugal and Slovakia).

5.2   Are there certain types of buildings for which specific design licences are required?

In most of the countries no, but in Finland, Poland, Portugal and Spain there are certain types of buildings for which specific design licenses are required.

5.3   Is the licence-holder an individual or an organisation?

In most of the countries the license is individual. In France and Hungary the license holder is an organization.

5.4   Is a specific insurance required?

In all the Countries a specific insurance is not required.

6. Precedence of performance-based fire engineering projects

6.1   Project details.

It depends on the Country the amount of the details. Normally are the temperature of the compartment according to the adopted fire scenario, and calculation in agreement with the standards.

6.2   What was performance-based?

In most cases the fire scenario and structural fire behaviour, but also the evacuation time of the building.

6.3   What techniques where used to justify the non-compliance?

Normally Fire Safety Engineering.

6.4   What approvals route was used?

Usual route through the authorities.

7. Passive fire protection

7.1   What are the possible product approvals of fire protection materials and methods (National, ETA or CE marking)?

In most of the Countries products with CE making, but in some Countries (Belgium, Finland, Germany, Poland, Spain and UK) National and/ ETA products can also be used.

If there are any mistakes in these answers, or changes needed, the writers ask the readers kindly to send comments and corrections to: Professor Paulo Vila Real [pvreal@ua.pt].

Responses:

The following table shows the colleagues who returned the questionnaire.

Country	Family name	First name	Institution
Belgium	DE NAEYER *	Andre	Association University & Hogeschool Antwerpen
CZ	KUČERA*	Petr	Technical University of Ostrava
Finland	OUTINEN *	Jyri	Ruukki Construction
France	DHIMA *	Dhionis	CSTB - Département Sécurité, Structure et Feu
Germany	KIRSCH *	Thomas	Institute for Steel Construction
Greece	MISTAKIDIS *	Euripdis	University of Thessaly
Hungary	SZILAGYI *	Csaba	OPTOMM Kft.
Italy	MAZZOLANI *	Federico	University of Naples "Federico II"
Poland	KOWALSKI *	Robert	Warsaw University of Technology
Portugal	VILA REAL *	Paulo	University of Aveiro
Slovakia	VARGOVSKY *	Kamil	
Spain	MARIMON *	Frederic	Universitat Politècnica de Catalunya
UK	JENKINS *	Paul	London Fire Brigade

Questionnare responses from WG3 Members

BUILDING REGULATIONS

Question 1.1: Prescriptive or performance-based

Are the Building Regulation prescriptive or performance-based (i.e. is it possible to design from first principles using finite element analysis, CFD, etc to show that the intents of the Building Regulations are met?)

Answers:

BELGIUM

The regulations are prescriptive. For industrial buildings: mixture of prescriptive & performance-based design and use some calculation methods.

CZECH REPUBLIC

The regulation allows performance-based design and use of advanced calculation methods (technical expertise). Law No. 133/1985 Coll. on fire protection (Section 99): Certified engineer in fire protection can use during the design of fire safety of building approach which is determined by technical standart or another technical document of fire protection.

FINLAND

The regulation allows both: design based on prescriptive rules, performance-based design and use of advanced calculation methods.

FRANCE

The building regulation is mostly prescriptive, but allows performance-based design and use of advanced calculation methods.

GERMANY

The regulations in exceptionally allow performance-based design and use of advanced calculation methods. These methods have to be discussed with the public authorities for every project.

GREECE

The regulation doesn't allow the use of advanced calculation methods (finite element analysis, CFD, etc)

HUNGARY

The regulations are really prescriptive.

ITALY

The regulations are basically prescriptive and concern several types of building use. However, the performance-based design and advanced calculation methods may be applied either in the lack of prescriptive rules or in the case of "derogation" with respect to prescriptive rules.

POLAND

Generally building regulations are still prescriptive, but they allow performance-based design and use of advanced calculation methods.

PORTUGAL

The regulation allows performance-based design and use of advanced calculation methods.

SLOVAKIA

Is not possible to use the engineering access.

SPAIN

There are excellent codes in Spain based in modern concepts of Fire Engineering in harmony with European regulations. Spanish designers can use advanced models with supervision of local officers.

UNITED KINGDOM

The regulation allows performance-based design and use of advanced calculation methods.

Question 1.2: Relevant Building Regulations

What are the Building Regulations relevant for fire called and who is the issuing body?

Answers:

<u>**BELGIUM**</u>

Les Normes de Base:

<u>7 Juillet 1994. - Arrêté royal fixant les normes de base en matière de prévention contre l'incendie et l'explosion, auxquelles les bâtiments nouveaux doivent satisfaire plus modifications</u>

Plus a lot of regulations for all sort of building types such as hotels, hospitals, homes for elderly people...

<u>**CZECH REPUBLIC**</u>

<u>Law No. 133/1985 Coll., on Fire Protection</u>

This Law includes obligations of state authorities, legal and natural persons on fire protection field (e.g. classification of performed business by fire risk, content evaluation of fire risk)

<u>Decree No. 246/2001 Coll., on stipulation of fire safety conditions and on State fire supervision performance (Decree on fire prevention)</u>

- basic requirements of fire safety
- types of dedicated fire technique, fire protection material means and fire safety equipment
- requirements to Design and istallation of fire safety equipment
- type of fire protection documentation
- method of managing the fire protection documentation
- contents and scope of fire safety design etc.

<u>Decree No. 23/2008 Coll., on the technical requirements for the fire protection of buildings</u>

This Decree lays down the technical requirements for fire protection in the design, construction and use of buildings.

<u>**FINLAND**</u>

<u>The National Building Code of Finland, Series E, especially parts E1 and E2</u>, issued by the Finnish Ministry of the Environment. Link to page with unofficial English translations of said documents:

<u>http://www.ymparisto.fi/default.asp?contentid=357799&lan=fi&clan=en#a4</u>

Also the Finnish NA's to the Eurocodes are available on this page.

<u>**FRANCE**</u>

The principal document is "<u>Le code de la construction et de l'habitation: The Code of the Construction and the buildings</u>"

There are some d<u>é</u>crets :

<u>Décret n° 69-596 of 14-06-1969 which fix the general rules of construction of dwelling buildings</u>

<u>Décret n°67-1063 of 15-11-1967 which deals with the constructon of high-rise buildings and their fire protection</u>

Décret n°54-856 of 13-08-1954 retating to protection against the panic and fire hazards in the establishments receiving of the public.

The issuing body is the Direction of the Civil Safety of the Ministry for the Interior :

http://www.interieur.gouv.fr/sections/a_l_interieur/defense_et_securite_civiles/presentation/ddsc/view

GERMANY

For the reason that Germany is a federal state, every state (Bavaria, Lower Saxony, North-Rhine-Westphalia, etc.) has its own building regulations. All are based on the Musterbauordnung "MBO" which is a template and could be translated by "Master building regulation". The general requirements are written down there.

Fire resistance time for different structural members of buildings can be determined by DIN 4102. As the Eurocodes (parts 1-2) will be established, the DIN 4102 will become invalid

For industrial buildings according to Musterindustriebaurichtlinie (see below) there are calculation methods listed in DIN 18230.

GREECE

The main regulations are:

Greek Presidential Edict (71/88) 'Building Fire Protection'.- Greek Goverment Decision(no 5905/1995) 'Industrial Fire Protection'

HUNGARY

From the Ministry of Local Government:

9/2008. (II. 22.) ÖTM rendelet az Országos Tűzvédelmi Szabályzat kiadásáról

ITALY

Decree of the Republic President n.37, 12/01/1998, "Regolamento recante disciplina dei procedimenti relativi alla prevenzione incendi".

Decree of the Ministry of the Interior, 04/05/1998, "Disposizioni relative alle modalità di presentazione ed al contenuto delle domande per l'avvio dei procedimenti di prevenzione incendi, nonché all'uniformità dei connessi servizi resi dai Comandi Provinciali dei Vigili del Fuoco".

Decree of the Ministry of the Interior, 16/02/2007 "Classificazione di resistenza al fuoco di prodotti ed elementi costruttivi di opere da costruzione".

Decree of the Ministry of the Interior, 09/03/2007, "Prestazioni di resistenza al fuoco delle costruzioni nelle attività soggette al corpo nazionale dei vigili del fuoco".

Decree of the Ministry of the Interior, 09/05/2007 "Direttive per l'attuazione all'approccio ingegneristico alla sicurezza antincendio".

NUOVE NORME TECNICHE PER LE COSTRUZIONI, Decree of the Infrastructure Ministry 14/01/2008.

Infrastructure Ministry n.617 of 02/02/2009, "Istruzioni per l'applicazione delle Nuove Norme Tecniche di cui al DM 14 Gennaio 2008"

POLAND

Ustawa z dnia 7 lipca 1994 r. Prawo budowlane (Dz.U. z 2006 r. Nr 156, poz. 1118 z późn. zm.) – Sejm RP (Sejm of the Republic of Poland – Polish Parliment)

Ustawa z dnia 24 sierpnia 1991 r. o ochronie przeciwpożarowej (t.j. Dz. U. Nr 178 z 2009 r. poz. 1380 z późn. zm.) – Sejm RP (Sejm of the Republic of Poland – Polish Parliment)

Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 w sprawie warunków technicznych jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. Nr 75 z 2002 r, poz. 690 z póżn. zm.) – Ministerstwo Infrastruktury (Ministry of Infrastructure)

Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 7 czerwca 2010 roku w sprawie ochrony przeciwpożarowej budynków, innych obiektów budowlanych i terenów (Dz. U. Nr 109, poz. 719) – Ministerswo Spraw Wewnętrznych i Administracji (Ministry of the Interior and Administration).

PORTUGAL

The law Decreto-Lei n.º 220/2008, de 12 de Novembro, which establishs the juridical rules for buildings fire safety Regime Jurídico da Segurança Contra Incêndio em edifícios (RJ-SCIE);

Technical regulation for buildings fire safety Regulamento Técnico de Segurança contra Incêndio em Edifícios e Recintos (RT-SCIE), que constitui a Portaria n.º 1532/2008, de 29 de Dezembro de 2008;

Despacho n.º 2074/2009, de 15 de Janeiro, do Presidente da Autoridade Nacional de Protecção Civil on the technical criteria for determining the modified fire load density.

SLOVAKIA

The law n.º 314/2001; The protection for the fires;

Announcement of Ministry of Interior of the Slovak Republic n. 121/2002; The fire prevention

Part of government, which prepare jurical decree is Ministry of Interior of the Slovak Republic. In the law 314/2001 are the basic duty on the part of protection for the fire and the details solve the Annoucements of Ministry of interior of the Slovak Republic with technical contents;

Fire security of buildinds solve the Announcement of MI SR, n. 94/2004, which describe the technical requests on fire protection by the construction of building, so by the using of buildings

SPAIN

We have two relevant codes in Spain;

The Spanish Technical Building Code (CTE) for residential, commercial and administrative buildings, from Ministry for Housing. It's a true performance-based code but it has the prescriptive rules too.

CTE - Código Técnico de la Edificación

http://www.codigotecnico.org/web/cte/

A second code for industrial buildings is the Spanish Security Code against to Fire in Industrial Activities (RSIEI) from Ministry of Industry, Tourism and Trade. It's a specific legislation for industrial safety.

RSIEI - Reglamento de Seguridad contra Incendios en los Establecimientos Industriales

http://www.ffii.nova.es/puntoinfomcyt /Archivos/Dis_4539.pdf

UNITED KINGDOM

2010 No. 2214 - Building And Buildings, England And Wales - The Building Regulations 2010

2010 No. 2215 - Building And Buildings, England And Wales - The Building (Approved Inspectors etc.) Regulations 2010

Question 1.3:   Additional guidance

Is there additional guidance available to interpret the Building Regulations for fire?

Answers:

BELGIUM

Not answered.

CZECH REPUBLIC

Fire rescue service of Czech Republic provides some technical notes on fire safety of building.

For example interpretation of laws about fire protection:

http://www.hzscr.cz/clanek/odpovedi-na-nejcastejsi-dotazy.aspx

FINLAND

Guidance is available in Finnish and Swedish, e.g.

Ympäristöopas 39 (YO39 Rakennusten paloturvallisuus & Paloturvallisuus korjausrakentamisessa) – a guidebook related to E1 / In Finnish and Swedish.

RIL 221-2003 Paloturvallisuussuunnittelu (guidebook on fire safety engineering design) / In Finnish

FRANCE

No.

GERMANY

Yes. For every state building regulations comments and reasons exist.

GREECE

No.

HUNGARY

We have some national pre standards

1. MSZE 595-1:2009 Építmények tűzvédelme. 1. rész: Fogalommeghatározások

2. MSZE 595-3:2009 Építmények tűzvédelme. 3. rész: Épületszerkezetek tűzállósági követelményei

3. MSZE 595-5:2009 Építmények tűzvédelme. 5. rész: Tűzszakaszolás, tűzterjedés elleni védelem

4. MSZE 595-6:2009 Építmények tűzvédelme. 6. rész: Kiürítés

5. MSZE 595-7:2009 Építmények tűzvédelme. 7. rész: A számított tűzterhelés és a mértékadó tűzidőtartam meghatározása

6. MSZE 595-8:2009 Építmények tűzvédelme. 8. rész: Hő és füst elleni védelem

7. MSZE 595-9:2009 Építmények tűzvédelme. 9. rész: Robbanási túlnyomás lefúvatása

ITALY

No, in Italy there isn't a guide available to interpret the Building Regulations for fire. However, the National Body of Fire provides some technical notes (named "Lettere Circolari") related to several decrees.

POLAND

Some instructions are published by Instytut Techniki Budowlanej (Building Research Institute)

PORTUGAL

ANPC – National Authority of Civil Protection, provides some technical notes on fire safety of buildings:

http://www.prociv.pt/Pages/Detalhe4.aspx?IDitem=41

SLOVAKIA

The basic requests are described in juristical decree – announcements. Concrete requests specify the Slovak technical standards.

SPAIN

Yes, there are some guides and FAQ's to interpret the practical application of these rules. In several cases this additional information is very relevant.

CTE

http://www.codigotecnico.org/web/cte/faqs/

RSIEI - Technical Guide

http://www.ffii.nova.es/puntoinfomcyt/Archivos /InstProtInc/GUIA_TECNICA_RSCI.pdf

UNITED KINGDOM

Practical guidance on ways to comply with the functional requirements in the Building Regulations is outlined in a series of 'Approved Documents' published by the Department for Communities and Local Government.

Each document contains:

- general guidance on the performance expected of materials and building work in order to comply with each of the requirements of the Building Regulations; and

- practical examples and solutions on how to achieve compliance for some of the more common building situations.

All of the latest 'Approved Documents' can be downloaded free on the Planning Portal at:

www.planningportal.gov.uk/approveddocuments

Question 1. 4: Different regulations for certain types of buildings

Are there different regulations for certain types of buildings (I.e. schools, hospitals, airports, railway stations)?

Answers:

<u>**BELGIUM**</u>

Yes, for every type of buildings there is a different regulation:

- Industrial buildings (part of "les norms de base")

- Hospitals,

- All sort of different hotels

- All sort of different homes for elderly people,

- Schools,

- Homes for youngsters

- Homes for disabled people

- Homes for childcare

- ...

<u>**CZECH REPUBLIC**</u>

<u>Decree No. 23/2008 Coll., on the technical requirements for the fire protection of buildings</u>

This Decree specifies basic technical requirements for following types of buildings:

1. Family homes and buildings for family recreation
2. Apartment buildings
3. Hostel buildings
4. Health care and social welfare buildings
5. Buildings with assembly areas
6. Lookout tower buildings
7. Garage buildings
8. Filling station, servicing and repair buildings
9. Buildings used for school and educational establishment activities
10. Agricultural buildings
11. Production and storage buildings
12. Listed buildings
13. Building site buildings

FINLAND

Buildings are categorised into three fire classes, P1, P2 and P3, based on the use, size and occupancy of the building. P1 is the highest class and these buildings are usually not allowed to suffer structural collapse due to a fire.

Schools, hospitals, airports etc. are usually Class P1 buildings due to their size and the amount of people using them.

FRANCE

There are some other regulations:

Arrêté du 31-01-1986, relating to the protection of the apartment buildings against fire.

Arrêté du 25-06-1980, retating to protection against the panic and fire hazards in the establishments receiving the public.

Arrêté du 18-10-1977, retating to protection against the panic and fire hazards in the high-rise buildings.

There are different regulations (arêtes) for:

- Car parks
- Industrial installation,
- Warehouse,
- Nuclear installations

GERMANY

As mentioned above, every state has its own code in Germany. This is the same for every building type code. The list includes the "template-versions":

Musterindustriebaurichtlinie (industrial buildings)

Mustergaragenverordnung (car parks)

Musterversammlungsstättenverordnung (meeting halls)

Musterverkaufsstättenverordnung (shopping centres)

Musterschulbauorndnung (schools)

Musterbeherbergungsstaättenverordnung (hotels)

Musterkrankenhausbauverordnung (abandoned, hospitals)

GREECE

Greek Presidential Edict (71/88), Section 1, covers the following utilization-types of buildings :

- Type I   «Dwelling»
- Type II « Hotels
- Type III «Schools»
- Type IV «Offices»
- Type V «Shops»
- Type VI «Places of public meetings»
- Type VII «Industrial, workshops and storage»

- Type VIII «Hospitals and nursing homes»

- Type IX   «Parking places and fuel stations»

HUNGARY

We use different groups according the fire resistance of the building materials.

In the first group there are high-rise buildings, and the middle high-rise buildings if there is in a crowd staying room above 13m.

In the second group there are kindergartens, social homes, closed garages, handicap people staying room if the building is taller than 2 floor, middle high-rise buildings, buildings which are not in the first group with the two and three underground floors.

In the third group there are schools, living buildings which taller than 2 level, community buildings if the top floor is not over 13,65m, more than one floors open garages, handicap people staying room.

In the forth group the one floor living and holiday buildings, the one floor community buildings minimum 25 maximum 50 person.

In the fifth group, maximum ground floor living and holiday buildings maximum 25 person.

ITALY

The Decree of the Ministry of Interior 16/02/1982 ("Modificazioni del decreto ministeriale 27 settembre 1965, concernente la determinazione delle attività soggette alle visite di prevenzione incendi") defines 97 types of building use, which are subjected to the control of the Fire Brigades.

For many building uses the Ministry provides specific Technical Rules of Fire Fighting, generally based on a prescriptive approach.

POLAND

Regulations are general for all kinds of buildings, nevertheless they divide building into three main groups:

- Housing and public utility buildings; involving endangering people (ZL)

- Production plants and warehouses (PM)

- Agricultural (IN)

PORTUGAL

The RJ-SCIE covers the following twelve utilization-types:

- Type I «Dwelling»

- Type II «Car parks»

- Type III «Administrative»

- Type IV «Schools»

- Type V «Hospitals and nursing homes»

- Type VI «Theatres/cinemas and public meetings»

- Type VII «Hotels and restaurants»

- Type VIII «Shopping and transport centres»

- Type IX «Sports and leisure»

- Type X «Museums and art galleries»

- Type XI «Libraries and archives»

- Type XII «Industrial, workshops and storage»

Due to the big dimension in plan and height the building can be classified as "atypical danger".

SLOVAKIA

Yes they are specified in technical decrees:

Announcements of MI SR n.94/2004 – there are described technical requests on Fire safety by construction and using of the buildings.

Announcements of MI SR n.96/2004, there are described principles fire protection by manipulation and the storage of flammable liquids, hard fuel oils and flowers and animal fat and oils.

Announcements of MI SR n.121/2002 – about fire prevention

Announcements of MI SR n.124/2000- here by the work with the flammable gasses

Announcements of MI SR n.142/2004 about the fire safety by the construction and using the spaces, where are used pain materials.

Announcements of MI SR n.258/2007 about demands of fire security by the storage and manipulation with solid flammable materials.

SPAIN

The Spanish Technical Building Code (CTE) covers the most types of buildings.

The industrial building or big storage building are covered by the Spanish Security Code against to Fire in Industrial Activities (RSIEI).

Specific activities are out of both codes, for instance; nuclear or mineral extraction.

UNITED KINGDOM

2 (a) Institutional

2 (a) Other residential: a. in bedrooms; b. in bedrooms corridors; c. elsewhere

3 office

4 Shop and commercial

5 Assembly and recreation: a. building primarily for disabled people; b. areas with seating in rows; c. elsewhere

6. Industrial: normal hazard; higher hazard

7. Storage and other non-residential: normal hazard; higher hazard

2-7 Place of special fire hazard

2-7 Plant room or rooftop plant: a. distancewithin the room; b. escape route not in open air (overall travel distance); c. escape route in open air (overall travel distance)

DESIGN CODES

Question 2.1a: Relevant national or international/European standards - Means of escape

What are the relevant national or international/European standards required to undertake the design of: means of escape?

Answers:

BELGIUM

There are no relevant standards on this matter.

CZECH REPUBLIC

CSN 73 0802 - Fire protection of buildings - Non-industrial buildings

CSN 73 0804 - Fire protection of buildings - Industrial buildings

FINLAND

No information on design standards, but the relevant regulations include:

National decree No. 805/2005 concerning lighting and signalling of escape routes, in Finnish.

Regulations given also in Finnish National Building Code Part E1 Chapter 10 (see link above).

FRANCE

There are no relevant standards on this matter.

GERMANY

Musterbauordnung and regulation for certain type of building.

GREECE

There are no relevant standards on this matter.

HUNGARY

There are no relevant standards on this matter.

ITALY

There are national standards depending on the use of building (within the quoted prescriptive technical rules of fire fighting concerning the specific building use).

POLAND

Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 w sprawie warunków technicznych jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. Nr 75 z 2002 r, poz. 690 z póżn. zm.) – Ministerstwo Infrastruktury (Ministry of Infrastructure)

Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 7 czerwca 2010 roku w sprawie ochrony przeciwpożarowej budynków, innych obiektów budowlanych i terenów (Dz. U. Nr 109, poz. 719) – Ministerswo Spraw Wewnętrznych i Administracji. (Ministry of the Interior and Administration).

PN-ISO 8421-6 Ochrona przeciwpożarowa. Terminologia. Ewakuacja i środki ewakuacji.

PN-92/N-01256/02 Znaki bezpieczeństwa. Ewakuacja.

PORTUGAL

There are no relevant standards on this matter.

SLOVAKIA

The escape ways, which are saved for the fire and secured with air ventilation.

SPAIN

Section SI-3 of CTE is devoted to provision of a safe route(s) for emergency evacuation by horizontal and vertical escape.

Moreover, RSIEI has additional requirements for industrial buildings.

UNITED KINGDOM

BS EN's or Eurocodes primarily, but functional regulations so any guidance permissible.

Question 2.1b: Relevant national or international/European standards - Smoke management

What are the relevant national or international/European standards required to undertake the design of: smoke management?

Answers:

BELGIUM

There is not a general legislation only a these standards

NBN S 21-208-1 : 1995 - Protection incendie dans les bâtiments - Conception et calcul des installations d'évacuation de fumées et de chaleur (EFC) - Partie 1 : Grands espaces intérieurs non cloisonnés s'étendant sur un niveau

NBN S 21-208-2 : 2006 - Protection incendie dans les bâtiments - Conception des systèmes d'évacuation des fumées et de la chaleur (EFC) des bâtiments de parking intérieurs

NBN S 21-208-2/prA1 : 2010 - Protection incendie dans les bâtiments - Conception des systèmes d'évacuation des fumées et de la chaleur (EFC) des parkings fermé

CZECH REPUBLIC

CSN 73 0802 - Fire protection of buildings - Non-industrial buildings (Annex H – natural smoke and heat exhaust)

CSN P CEN/TR 12101-5 - Smoke and heat control systems - Part 5: Guidelines on functional recommendations and calculation methods for smoke and heat exhaust ventilation systems

FINLAND

No information on design standards, but the relevant regulations include:

Regulations given in Finnish National Building Code Part E1 Chapter 11 (see link above).

FRANCE

There are :

Technical instruction n° 246, relating to receiving smoke clearing in the establishments of the public.

Technical instruction n° 263 relating to the construction and the receiving smoke clearing of interior free volumes (atriums) in the establishments of the public

GERMANY

VFDB-guideline, Muster-Versammluingsstättenverordnung, Muster-Industriebaurichtlinie

GREECE

There are no specific regulations on this matter.

HUNGARY

We use MSZ EN 12101 Smoke and heat control system standard.

ITALY

There are national standards depending on the use of building (within the quoted prescriptive technical rules of fire fighting concerning the specific building use).

POLAND

Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 w sprawie warunków technicznych jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. Nr 75 z 2002 r, poz. 690 z póżn. zm.) – Ministerstwo Infrastruktury (Ministry of Infrastructure)

PN-B-02877-4 Ochrona przeciwpożarowa budynków -- Instalacje grawitacyjne do odprowadzania dymu i ciepła -- Zasady projektowania. (Fire protection of buildings - Installation of gravitational devices for smoke and heat drainage - Design rules

PN-EN-12101-1 System kontroli rozprzestrzeniania dymu i ciepła – Część 1: Wymagania techniczne dotyczące kurtyn dymowych. (Smoke and heat control systems -- Part 1: Specification for smoke barriers.)

PN-EN-12101-2 System kontroli rozprzestrzeniania dymu i ciepła – Część 2: Wymagania techniczne dotyczące klap dymowych. (Smoke and heat control systems -- Part 2: Specification for natural smoke and heat exhaust ventilators.)

PN-EN-12101-3 System kontroli rozprzestrzeniania dymu i ciepła – Część 3: Wymagania techniczne dotyczące wentylatorów oddymiających. (Smoke and heat control systems -- Part 3: Specification for powered smoke and heat exhaust ventilators.)

PN-EN-12101-6 System kontroli rozprzestrzeniania dymu i ciepła – Część 6: Wymagania techniczne dotyczące systemów różnicowania ciśnień -- Zestawy urządzeń (Smoke and heat control systems -- Part 6: Specification for pressure differential systems – Kits.)

PN-EN-12101-10 System kontroli rozprzestrzeniania dymu i ciepła – Część 10: Zasilacze (Smoke and heat control systems -- Part 10: Power supplies.)

PORTUGAL

There are no specific regulations on this matter but documents / different rules, for example, the NFPA and APSARD.

SLOVAKIA

Systems for offtake of heat and combustion gasses. The rules are from the producers or from Slovak Technical Standards 12101. Accepted are technical standards DIN, NFS and the directions VDS.

SPAIN

The Article 8 of Section SI-3 of CTE to remit to national standard UNE 23585:2004 and to Euronorm EN 12101-6:2005 for smoke and heat control systems.

Nowadays, this Euronorm is Spanish standard UNE-EN 1991-1-2:2004 since 2006.

The Annex II of RSIEI has additional requirements and allows using others international standards.

UNITED KINGDOM

BS EN's or Eurocodes primarily, but functional regulations so any guidance permissible

Question 2.1c:Relevant national or international/European standards - Fire resistance of the construction

What are the relevant national or international/European standards required to undertake the design of: Fire resistance of the construction?

Answers:

BELGIUM

There is a standard for the fire resistance of

NBN 713-020 Protection contre l'incendie - Comportement au feu des matériaux et éléments de construction - Résistance au feu des éléments de construction

Part 1.2 (Structural fire design) from Eurocodes.

CZECH REPUBLIC

Requirements on fire resistance:

CSN 73 0802 - Fire protection of buildings - Non-industrial buildings

CSN 73 0804 - Fire protection of buildings - Industrial buildings

CSN 73 0810 - Fire protection of buildings - General requirements

Eurocodes.- Part 1.2 (Structural fire design)

CSN 73 0821 - Fire protection of buildings - Fire resistance of engineering structures

FINLAND

Parts 1.2 (Structural fire design) of the Eurocodes (or the Finnish National Building Code Series B, for as long as it is valid (probably until spring 2011)).

FRANCE

Part 1.2 (Structural fire design) from Eurocodes.

GERMANY

Part 1.2 (Structural fire design) from Eurocodes, DIN 4102.

GREECE

National *prescriptive rules* require a certain standard *fire resistance* of walls and floors, depending on their use and geometry.

HUNGARY

(Structural fire design) from Eurocodes.

ITALY

The Decree of the Ministry of the Interior, 16/02/2007 ("Classificazione di resistenza al fuoco di prodotti ed elementi costruttivi di opere da costruzione") is applicable to assess the fire resistance of the building. In addition, the Decree allows the use of the Parts 1.2 of the relevant Eurocodes.

POLAND

Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 w sprawie warunków technicznych jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. Nr 75 z 2002 r, poz. 690 z póżn. zm.) – Ministerstwo Infrastruktury (Ministry of Infrastructure)

Eurocodes: Part 1.2 (Structural fire design).

Other codes (based on European codes)

PN-EN 1363-1:2001 Badania odporności ogniowej -- Część 1: Wymagania ogólne (Fire resistance test – Part 1: General requirements)

PN-EN 1364-1:2001 Badania odporności ogniowej elementów nienośnych -- Część 1: Ściany (Fire resistance tests for non-loadbearing elements: Part 1: Walls)

PN-EN 1365-1:2001 Badania odporności ogniowej elementów nośnych -- Część 1: Ściany (Fire resistance tests for loadbearing elements: Part 1: Walls)

Other parts of PN-EN 1363, 1364, 1365.

PORTUGAL

Part 1.2 (Structural fire design) from Eurocodes.

SLOVAKIA

(Structural fire design) is from estimation of proof or calculation with help of Eurocodes.

SPAIN

Section SI-6 of CTE is devoted to requirements for structural fire resistance and his verification for several structural materials:

Annex C Concrete Structures

Annex D Steel Structures

Annex E Timber Structures

Annex F Masonry

The Spanish rules for structural verification under fire are very similar of the rules of Eurocodes

UNITED KINGDOM

BS EN's or Eurocodes primarily but functional regulations so any guidance permissible.

Question 2.1d: Relevant national or international/European standards - Fire fighting

What are the relevant national or international/European standards required to undertake the design of: Fire fighting?

Answers:

BELGIUM

Portable fire extinguishers

The NBN S21-011 to NBN S21-018 range should have been replaced by the NBN EN3 -1 to EN3-6. Because the Dutch version of EN3 doesn't exist, the NBN preserved this range (against all CEN-rules). These standards have become obsolete. In practice, most fire extinguishers are in accordance with the EN3 ranges, of which the last valid standard is the EN3-7: 2004

Numéro de norme	Titre	Date de publication	Langue	Statut
NBN S 21-011/A1 : 1977	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Prescriptions communes applicables à tous les types d'extincteurs	1977	NL/FR	Actif
NBN S 21-011/A2 : 1977	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Prescriptions communes applicables à tous les types d'extincteurs	1977	NL/FR	Actif
NBN S 21-011/A3 : 1987	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Prescriptions communes applicables à tous les types d'extincteurs	1987	NL/FR	Actif
NBN S 21-011/A4 : 1988	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Prescriptions communes applicables à tous les types d'extincteurs	1988	NL/FR	Actif
NBN S 21-011 : 1974	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Prescriptions communes applicables à tous les types d'extincteurs	1974	NL/FR	Actif
NBN S 21-012 : 1974	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Extincteurs à eau	1974	NL/FR	Actif
NBN S 21-013 : 1974	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Extincteurs à réaction chimique	1974	NL/FR	Actif
NBN S 21-014 : 1974	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Extincteurs à poudre	1974	NL/FR	Actif
NBN S 21-015/A1 : 1977	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Extincteurs à anhydride carbonique (CO2)	1977	NL/FR	Actif
NBN S 21-015/A2 : 1987	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Extincteurs à anhydride carbonique (CO2)	1987	NL/FR	Actif
NBN S 21-015 : 1974	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Extincteurs à anhydride carbonique (CO2)	1974	NL/FR	Actif
NBN S 21-016/A1 : 1977	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Extincteurs à hydrocarbures halogénés	1977	NL/FR	Actif
NBN S 21-016 : 1974	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Extincteurs à hydrocarbures halogénés	1974	NL/FR	Actif
NBN S 21-017/A1 : 1977	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Foyers-types et puissance minimale d'extinction	1977	NL/FR	Actif
NBN S 21-017/A2 : 1987	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Foyers-types et puissance minimale d'extinction	1987	NL/FR	Actif
NBN S 21-017 : 1974	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie portatifs - Foyers-types et puissance minimale d'extinction	1974	NL/FR	Actif
NBN S 21-018 : 1974	Matériel de sauvetage et de lutte contre l'incendie - Extincteurs d'incendie - Essai de vibration - Essai d'efficacité - Essai diélectrique - Procès-verbal d'essai - Certificat d'agrément	1974	NL/FR	Actif

CZECH REPUBLIC

CSN 73 0873 - Fire protection of buildings - Eqipment for fire-water supply (Annex B – Fundamentals for analyses fire fighting)

FINLAND

No information on design standards, but the relevant regulations include:

Regulations given in Finnish National Building Code Part E1 Chapter 11 (see link above).

FRANCE

There are no relevant standards on this matter.

GERMANY

Fw DV 3, Fw DV 4 (fire brigade codes), Fire Protection Law

GREECE

There are no relevant standards on this matter.

HUNGARY

There are no relevant standards on this matter.

ITALY

There are national standards depending on the use of building (within the quoted prescriptive technical rules of fire fighting concerning the specific building use).

POLAND

Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 7 czerwca 2010 roku w sprawie ochrony przeciwpożarowej budynków, innych obiektów budowlanych i terenów (Dz. U. Nr 109, poz. 719) – Ministerswo Spraw Wewnętrznych i Administracji (Ministry of the Interior and Administration).

Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 24 lipca 2009 r. w sprawie przeciwpożarowego zaopatrzenia w wodę oraz dróg pożarowych (Dz.U. Nr 124, poz. 1030).

Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 29 grudnia w sprawie szczegółowych zasad organizacji krajowego systemu ratowniczo-gaśniczego (Dz. U. 111, poz.1311)

PN-B-02864 Ochrona przeciwpożarowa budynków. Przeciwpożarowe zaopatrzenie wodne. Zasady obliczania zapotrzebowania na wodę do zewnętrznego gaszenia pożaru.

PN-B-02865 Ochrona przeciwpożarowa budynków. Przeciwpożarowe zaopatrzenie wodne. Instalacja wodociągowa przeciwpożarowa.

PN-82/B-02857 Ochrona przeciwpożarowa w budownictwie. Przeciwpożarowe zbiorniki wodne. Wymagania ogólne.

PORTUGAL

There are no relevant standards on this matter.

SLOVAKIA

It is solved the adequate conditions for efficient of fire fighting units.

SPAIN

Section SI-5 of CTE is devoted to accessibility for fire fighting

UNITED KINGDOM

BS EN's or Eurocodes primarily but functional regulations so any guidance permissible.

Question 2.1e: Relevant national or international/European standards - Fire safety systems (alarm, suppression, …)

What are the relevant national or international/European standards required to undertake the design of: Fire safety systems (alarm, suppression, …)?

Answers:

<u>**BELGIUM**</u>

There are specific standards for only some demands in the regulations

<u>NBN EN 54 part 1,2,3,4,5,7,10,11,12,13,16,17,18, 20, 21, 23, 24, 25</u>; specifies requirements for all component parts of a fire alarm system

Numéro de norme	Titre	Date de publication	Langue	Statu
NBN EN 54-1 : 1996	Systèmes de détection et d'alarme Incendie - Partie 1: Introduction	05/1996	NL/FR/EN	Actif
NBN EN 54-2 : 1998	Systèmes de détection et d'alarme Incendie - Partie 2: Équipement de contrôle et de signalisation (+ AC:1999)	01/1998	FR/EN	Actif
NBN EN 54-2/A1 : 2007	Systèmes de détection et d'alarme Incendie - Partie 2: Équipement de contrôle et de signalisation	05/2007	FR/EN/DE	Actif
NBN EN 54-3 : 2001	Systèmes de détection et d'alarme Incendie - Partie 3 : Dispositifs sonores d'alarme feu	08/2001	FR/EN/DE	Actif
NBN EN 54-3/A1 : 2002	Systèmes de détection et d'alarme Incendie - Partie 3: Dispositifs sonores d'alarme feu	09/2002	FR/EN/DE	Actif
NBN EN 54-3/A2 : 2006	Systèmes de détection et d'alarme Incendie - Partie 3: Dispositifs sonores d'alarme feu	10/2006	FR/EN/DE	Actif
NBN EN 54-4 : 1998	Systèmes de détection et d'alarme Incendie - Partie 4: Équipement d'alimentation électrique (+ AC:1999)	01/1998	FR/EN	Actif
NBN EN 54-4/A1 : 2003	Systèmes de détection et d'alarme Incendie - Partie 4: Équipement d'alimentation électrique	04/2003	FR/EN/DE	Actif
NBN EN 54-4/A2 : 2006	Systèmes de détection et d'alarme Incendie - Partie 4 : Équipement d'alimentation électrique	12/2006	FR/EN/DE	Actif
NBN EN 54-5/A1 : 2002	Systèmes de détection et d'alarme Incendie - Partie 5: Détecteurs de chaleur - Détecteurs ponctuels	09/2002	FR/EN/DE	Actif
NBN EN 54-5 : 2001	Systèmes de détection et d'alarme Incendie - Partie 5: Détecteurs de chaleur - Détecteurs ponctuels	02/2001	NL/FR/EN/DE	Actif
NBN EN 54-7 : 2001	Systèmes de détection et d'alarme Incendie - Partie 7: Détecteurs de fumée - Détecteurs ponctuels fonctionnant suivant le principe de la diffusion de la lumière, de la transmission de la lumière ou de l'ionisation	02/2001	FR/EN/DE	Actif
NBN EN 54-7/A1 : 2002	Systèmes de détection et d'alarme Incendie - Partie 7: Détecteurs de fumée - Détecteurs ponctuels fonctionnant suivant le principe de la diffusion de la lumière, de la transmission de la lumière ou de l'ionisation	09/2002	FR/EN/DE	Actif
NBN EN 54-7/A2 : 2006	Systèmes de détection et d'alarme Incendie - Partie 7 : Détecteurs de fumée - Détecteurs ponctuels fonctionnant suivant le principe de la diffusion de la lumière, de la transmission de la lumière ou de l'ionisation	12/2006	FR/EN/DE	Actif
NBN EN 54-10 : 2002	Systèmes de détection et d'alarme d'Incendie - Partie 10 : Détecteurs de flamme - Détecteurs ponctuels	03/2002	FR/EN/DE	Actif
NBN EN 54-10/A1 : 2006	Systèmes de détection et d'alarme Incendie - Partie 10 : Détecteurs de flamme - Détecteurs ponctuels	03/2006	FR/EN/DE	Actif
NBN EN 54-11 : 2001	Systèmes de détection automatique d'Incendie - Partie 11 : Déclencheurs manuels d'alarme	08/2001	FR/EN/DE	Actif
NBN EN 54-11/A1 : 2006	Systèmes de détection et d'alarme Incendie - Partie 11 : Déclencheurs manuels d'alarme	03/2006	FR/EN/DE	Actif
NBN EN 54-12 : 2003	Systèmes de détection et d'alarme Incendie - Partie 12: Détecteurs de fumée - Détecteurs linéaires fonctionnant suivant le principe de la transmission d'un faisceau d'ondes optiques rayonnées	03/2003	FR/EN/DE	Actif
NBN EN 54-13 : 2005	Systèmes de détection et d'alarme Incendie - Partie 13 : Evaluation de la compatibilité des composants d'un système	10/2005	FR/EN/DE	Actif
NBN EN 54-16 : 2008	Systèmes de détection et d'alarme Incendie - Partie 16: Élément central du système d'alarme Incendie vocale	09/2008	FR/EN/DE	Actif
NBN EN 54-17 : 2006	Systèmes de détection et d'alarme Incendie - Partie 17 : Isolateurs de court-circuit (+ AC:2007)	03/2006	FR/EN/DE	Actif
NBN EN 54-17/AC : 2007	Systèmes de détection et d'alarme Incendie - Partie 17 : Isolateurs de court-circuit	10/2007		Actif
NBN EN 54-18 : 2006	Systèmes de détection et d'alarme Incendie - Partie 18: Dispositifs d'entrée/sortie (+ AC:2007)	03/2006	FR/EN/DE	Actif
NBN EN 54-18/AC : 2007	Systèmes de détection et d'alarme Incendie - Partie 18: Dispositifs d'entrée/sortie	01/2007		Actif
NBN EN 54-20 : 2006	Systèmes de détection et d'alarme Incendie - Partie 20 : Détecteurs de fumée par aspiration (+ AC:2008)	11/2006	FR/EN/DE	Actif
NBN EN 54-20/AC : 2008	Systèmes de détection et d'alarme Incendie - Partie 20 : Détecteurs de fumée par aspiration	11/2008		Actif
NBN EN 54-21 : 2006	Systèmes de détection et d'alarme Incendie - Partie 21: Dispositif de transmission de l'alarme feu et du signal de dérangement	11/2006	FR/EN/DE	Actif
NBN EN 54-23 : 2010	Systèmes d'alarme feu et de détection d'Incendie - Partie 23: Dispositifs d'alarme feu - Alarmes visuelles	08/2010	FR/EN/DE	Actif
NBN EN 54-24 : 2008	Systèmes de détection et d'alarme Incendie - Composants des systèmes d'alarme vocale - Partie 24 : Haut-parleurs	09/2008	FR/EN/DE	Actif
NBN EN 54-25 : 2008	Systèmes de détection et d'alarme Incendie - Partie 25: Composants utilisant des liaisons radioélectriques (+ AC:2010)	09/2008	FR/EN/DE	Actif
NBN EN 54-25/AC : 2010	Systèmes de détection et d'alarme Incendie - Partie 25: Composants utilisant des liaisons radioélectriques	09/2010		Actif

(over page)

NBN EN 12094: parts 1- 13, 16 specifies requirements for fixed firefighting systems:

Numéro de norme	Titre	Date de publication	Langue	Statut
NBN EN 12094-1 : 2003	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour installations d'extinction à gaz - Partie 1: Exigences et méthodes d'essais applicables aux dispositifs électriques automatiques de commande et de temporisation	10/2003	NL/FR/EN/DE	Actif
NBN EN 12094-2 : 2003	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour installations d'extinction à gaz - Partie 2: Exigences et méthodes d'essai pour les dispositifs non électriques de commande et de temporisation	06/2003	NL/FR/EN/DE	Actif
NBN EN 12094-3 : 2003	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour installations d'extinction à gaz - Partie 3: Exigences et méthodes d'essai pour dispositifs manuels de déclenchement et d'arrêt d'urgence	05/2003	NL/FR/EN/DE	Actif
NBN EN 12094-4 : 2004	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour installations d'extinction à gaz - Partie 4: Exigences et méthodes d'essai pour les vannes de réservoir et leurs déclencheurs	09/2004	FR/EN/DE	Actif
NBN EN 12094-5 : 2006	Installations fixes de lutte contre l'incendie - Eléments constitutifs des installations d'extinction à gaz - Partie 5: Exigences et méthodes d'essai pour vannes directionnelles haute et basse pression et leurs déclencheurs	10/2006	FR/EN/DE	Actif
NBN EN 12094-6 : 2006	Installations fixes de lutte contre l'incendie - Eléments constitutifs des installations d'extinction à gaz - Partie 6: Exigences et méthodes d'essai pour dispositifs non électriques de mise hors service	10/2006	FR/EN/DE	Actif
NBN EN 12094-7 : 2001	Installations fixes de lutte contre l'incendie - Eléments constitutifs des installations d'extinction à gaz - Partie 7: Exigences et méthodes d'essai pour les diffuseurs de systèmes à CO2	02/2001	FR/EN/DE	Actif
NBN EN 12094-7/A1 : 2005	Installations fixes de lutte contre l'incendie - Eléments constitutifs des installations d'extinction à gaz - Partie 7 : Exigences et méthodes d'essai pour les diffuseurs de systèmes à CO2	04/2005	FR/EN/DE	Actif
NBN EN 12094-8 : 2006	Installations fixes de lutte contre l'incendie - Eléments constitutifs des installations d'extinction à gaz - Partie 8: Exigences et méthodes d'essai pour raccords	10/2006	FR/EN/DE	Actif
NBN EN 12094-9 : 2003	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour installations d'extinction à gaz - Partie 9: Exigences et méthodes d'essai pour détecteurs spéciaux	05/2003	FR/EN/DE	Actif
NBN EN 12094-10 : 2003	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour installations d'extinction à gaz - Partie 10: Exigences et méthodes d'essai pour manomètres et contacts à pression	06/2003	FR/EN/DE	Actif
NBN EN 12094-11 : 2003	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour installations d'extinction à gaz - Partie 11: Exigences et méthodes d'essai pour dispositifs de pesée mécaniques	05/2003	FR/EN/DE	Actif
NBN EN 12094-12 : 2003	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour systèmes d'extinction à gaz - Partie 12: Exigences et méthodes d'essai pour dispositifs pneumatiques d'alarme	05/2003	FR/EN/DE	Actif
NBN EN 12094-13 : 2001	Installations fixes de lutte contre incendies - Eléments d'installation d'extinction à gaz - Partie 13: Exigences et méthodes d'essai pour clapet anti-retour (+AC:2002)	05/2001	FR/EN/DE	Actif
NBN EN 12094-13/AC : 2002	Installations fixes de lutte contre l'incendie - Eléments d'installation d'extinction à gaz - Partie 13: Exigences et méthodes d'essai pour clapets anti-retour	02/2002		Actif
NBN EN 12094-16 : 2003	Installations fixes de lutte contre l'incendie - Eléments constitutifs pour installations d'extinction à gaz - Partie 16: Exigences et méthodes d'essai pour dispositifs odorisants pour installations à CO2 basse pression	05/2003	FR/EN/DE	Actif

CZECH REPUBLIC

CSN EN 54 – x (Fire detection and fire alarm systems)

CSN 73 0875 - Fire protection of buildings – Design of fire detection systems

FINLAND

SFS-EN 12845 + A2 Kiinteät palonsammutusjärjestelmät. Automaattiset sprinklerilaitteistot. Suunnittelu, asennus ja huolto. (Fixed firefighting systems. Automatic sprinkler systems. Design, installation and maintenance)

prNS-INSTA 900-1: Residential sprinkler systems – Part 1: Design, installation and maintenance

CEA 4001 Sprinkler Systems: Planning and Installation

A national decree on extuingishing methods is under preparation.

CEN / TC 72 published standards, list available at

http://www.cen.eu/CEN/Sectors/TechnicalCommitteesWorkshops/CENTechnicalCommittees/Pages/Standards.aspx?param=6055&title=CEN%2FTC+72

CEA 4040 Fire Protection Systems - Specifications for automatic fire detection and fire alarm systems - Planning and Installation.

ST-ohjeisto 1 Paloilmoittimen suunnittelu, asennus, huolto ja kunnossapito 2009 (guidance in Finnish)

FRANCE

European standards and the NFPA documents.

GERMANY

EN 54, DIN 14675, DIN VDE 0833

GREECE

National standards and NFPA documents.

HUNGARY

European standards and the NFPA documents.

ITALY

There are national standards depending on the use of building (within the quoted prescriptive technical rules of fire fighting concerning the specific building use).

POLAND

Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 7 czerwca 2010 roku w sprawie ochrony przeciwpożarowej budynków, innych obiektów budowlanych i terenów (Dz. U. Nr 109, poz. 719) – Ministerswo Spraw Wewnętrznych i Administracji (Ministry of the Interior and Administration).

PN-EN 54-1 Systemy sygnalizacji pożarowej – Wprowadzenie. Fire detection and fire alarm systems – Part 1: Introduction.

PN-EN 54-2 Systemy sygnalizacji pożarowej – Część 2: Centrale sygnalizacji pożarowej. Fire detection and fire alarm systems – Part 2: Introduction.

PN-EN 54-3 Systemy sygnalizacji pożarowej -- Część 3: Pożarowe urządzenia alarmowe -- Sygnalizatory akustyczne.

PN-EN 54-4 Systemy sygnalizacji pożarowej -- Część 4: Zasilacze.

PN-EN 54-5 Systemy sygnalizacji pożarowej -- Część 5: Czujki ciepła -- Czujki punktowe.

PN-EN 54-7 Systemy sygnalizacji pożarowej -- Część 7: Czujki dymu -- Czujki punktowe działające z wykorzystaniem światła rozproszonego, światła przechodzącego lub jonizacji.

PN-EN 54-10 Systemy sygnalizacji pożarowej -- Częć10: Czujki płomienia -- Czujki punktowe.

PN-EN 54-11 Systemy sygnalizacji pożarowej -- Część 11: Ręczne ostrzegacze pożarowe.

PN-EN 54-12 Systemy sygnalizacji pożarowej -- Część 12: Czujki dymu -- Czujki liniowe działające z wykorzystaniem wiązki światła przechodzącego.

PN-EN 54-13 Systemy sygnalizacji pożarowej -- Część 13: Ocena kompatybilności podzespołów systemu.

PN-EN 54-16 Systemy sygnalizacji pożarowej -- Część 16: Dźwiękowe systemy ostrzegawcze – Centrale.

PN-EN 54-17 Systemy sygnalizacji pożarowej -- Część 17: Izolatory zwarć.

PN-EN 54-18 Systemy sygnalizacji pożarowej -- Część 18: Urządzenia wejścia/wyjścia.

PN-EN 54-20 Systemy sygnalizacji pożarowej -- Część 20: Czujki dymu zasysające.

PN-EN 54-21 Systemy sygnalizacji pożarowej -- Część 21: Urządzenia transmisji alarmów pożarowych i sygnałów uszkodzeniowych.

PN-EN 54-23 Systemy sygnalizacji pożarowej -- Część 23: Pożarowe urządzenia alarmowe -- Sygnalizatory optyczne.

PN-EN 54-24 Systemy sygnalizacji pożarowej -- Część 24: Dźwiękowe systemy ostrzegawcze – Głośniki.

PN-EN 54-25 Systemy sygnalizacji pożarowej -- Część 25: Urządzenia wykorzystujące łączność radiową.

PKN-CEN/TS 54-14 Systemy sygnalizacji pożarowej -- Część 14: Wytyczne planowania, projektowania, instalowania, odbioru, eksploatacji i konserwacji.

PN-EN 1838 Zastosowania oświetlenia -- Oświetlenie awaryjne. Lighting applications – Emergency lighting.

PN-EN 50172 Systemy awaryjnego oświetlenia ewakuacyjnego.

PN-EN 12845 Stałe urządzenia gaśnicze -- Automatyczne urządzenia tryskaczowe -- Projektowanie, instalowanie i konserwacja. Fixed firefighting systems – Automatic sprinkler systems – Design, installation and maintenance.

PN-EN 15004-1 Stałe urządzenia gaśnicze -- Urządzenia gaśnicze gazowe -- Część 1: Ogólne wymagania dotyczące projektowania i instalowania.

PN-EN 60849 Dźwiękowe systemy ostrzegawcze.

PORTUGAL

European standards and the NFPA documents.

SLOVAKIA

European standards.

SPAIN

Section SI-4 of CTE is devoted to fire safety systems. More requirements are described in Annex II of Spanish Security Code against to Fire in Industrial Activities (RSIEI) with reference to Euronormes

UNITED KINGDOM

BS EN's or Eurocodes primarily but functional regulations so any guidance permissible

Question 2.2: Use of Eurocodes or other international fire standards

Is it possible to use Eurocodes or other international fire standards in lieu of the local code?

Answers:

BELGIUM

Yes, but you must request a deviation. When documenting your file, you can apply these standards.

CZECH REPUBLIC

Yes.

FINLAND

Yes.

FRANCE

Yes.

GERMANY

Yes (in clearance with authorities).

GREECE

Yes.

HUNGARY

Yes. In some cases we have to use fire models prove the situation.

ITALY

Yes. At the present the National annexes have not yet been published; however, some Eurocodes (EN1992-1-2; EN1993-1-2; EN1994-1-2; EN1995-1-2) may be applied assuming the suggested values as NDPs.

POLAND

Yes.

PORTUGAL

Yes.

SLOVAKIA

Yes.

SPAIN

Yes, the Technical Guide of Spanish Security Code against to Fire in Industrial Activities (RSIEI) allows using Eurocode 2, 3, 4, 5, and 6 for checking structural fire resistance. The rules for structural verification under fire of CTE SI-6 are very similar of the rules of Eurocodes.

UNITED KINGDOM

Yes

Question 2.3: Translations of the fire parts of Eurocodes

Are there available the translations of the fire parts of Eurocodes? Which ones?

Answers:

BELGIUM

NBN	EN	1991-1-2	FR	GE	NL
NBN	EN	1992-1-2	FR	GE	NL
NBN	EN	1993-1-2	FR	GE	NL
NBN	EN	1994-1-2	FR	GE	NL
NBN	EN	1995-1-2	FR	GE	NL
NBN	EN	1996-1-2	FR	GE	
NBN	EN	1999-1-2	FR	GE	

CZECH REPUBLIC

CSN	EN	1991-1-2	Yes
CSN	EN	1992-1-2	Yes
CSN	EN	1993-1-2	Yes
CSN	EN	1994-1-2	Yes
CSN	EN	1995-1-2	Yes
CSN	EN	1996-1-2	Yes
CSN	EN	1999-1-2	Yes

FINLAND

SFS	EN	1991-1-2	Yes
SFS	EN	1992-1-2	Yes
SFS	EN	1993-1-2	Yes
SFS	EN	1994-1-2	Yes
SFS	EN	1995-1-2	Yes
SFS	EN	1996-1-2	Yes
SFS	EN	1999-1-2	No

Available for purchase at http://sales.sfs.fi

FRANCE

NBN	EN	1991-1-2	Yes
NBN	EN	1992-1-2	Yes
NBN	EN	1993-1-2	Yes
NBN	EN	1994-1-2	Yes

NBN	EN	1995-1-2	Yes
NBN	EN	1996-1-2	Yes
NBN	EN	1999-1-2	Yes

GERMANY

Yes.

GREECE

No.

HUNGARY

No.

ITALY

No, the translations of the final versions of the Eurocodes are not yet available at the present.

POLAND

PN	EN	1990	Yes
PN	EN	1991-1-2	Yes
PN	EN	1992-1-2	Yes
PN	EN	1993-1-2	Yes
PN	EN	1994-1-2	Yes
PN	EN	1995-1-2	Yes
PN	EN	1996-1-2	Yes
PN	EN	1999-1-2	Will be available soon

PORTUGAL

NP	EN	1991-1-2	Yes
NP	EN	1992-1-2	Yes
NP	EN	1993-1-2	Yes
NP	EN	1994-1-2	No. Will be available soon
NP	EN	1995-1-2	No. Will be available soon
NP	EN	1996-1-2	No. Will be available soon
NP	EN	1999-1-2	No. Will be available soon

SLOVAKIA

STN	EN	1991-1-2	Yes
STN	EN	1992-1-2	Yes
STN	EN	1993-1-2	Yes
STN	EN	1994-1-2	Yes

STN	EN	1995-1-2	Yes
STN	EN	1996-1-2	Yes
STN	EN	1999-1-2	Yes

SPAIN

The Spanish translations of Eurocodes are managed by AENOR (Asociación Española de Normalización) and they are adapted as Spanish standard UNE-EN. These translations UNE-EN are available in paper or electronic format.

Nowadays, the state of relevant documents is as follows:

UNE	EN	1991-1-2:2004	Available since 14/05/2004
UNE	EN	1992-1-2	Only ENV available
UNE	EN	1993-1-2	Preprint. Will be available soon
UNE	EN	1994-1-2	Only ENV available
UNE	EN	1995-1-2	Only ENV available
UNE	EN	1996-1-2	Only ENV available
UNE	EN	1999-1-2	Only ENV available

UNITED KINGDOM

Not applicable.

Question 2.4: National annexes

Are the national annexes available in internet?

Answers:

BELGIUM

No. The national annexes are part of the translations of the Eurocodes. You have to command them via the NBN.

CZECH REPUBLIC

No. The national annexes are part of the Czech translations of the Eurocodes.

FINLAND

Yes, at:

http://www.ymparisto.fi/default.asp?contentid=357799&lan=fi&clan=en#a4

FRANCE

No. The national annexes are part of French Office of Standardisation AFNOR: http://www.afnor.org/

GERMANY

No

GREECE

Yes. Many national annexes are available at the internet site : www.fireservice.gr

HUNGARY

Yes. The fire code is a law so we can use it free.

ITALY

No, the national annexes were discussed and approved by a National Committee, but they have not yet been published.

POLAND

No. The national annexes are part of the Polish translations of the Eurocodes.

PORTUGAL

No. The national annexes are part of the Portuguese translations of the Eurocodes.

SLOVAKIA

No the standards are not available on internet.

SPAIN

No.

UNITED KINGDOM

Yes.

APPROVALS PROCESS

Question 3.1: Route to get a project approved

What is the normal route to get a project approved?

Answers:

BELGIUM

Via a public body.

CZECH REPUBLIC

Via a public body.

FINLAND

Via a public body.

FRANCE

Via a public body. Local fire safety commission and with a favourable opinion of a notified body for not prescriptive fire safety engineering projects.

GERMANY

Via a public body.

Via a private body. In eastern and some northern federal states by inspection engineers.

GREECE

Via a public body.

HUNGARY

Via a public body.

Self-certified. It depends the type of the licence.

ITALY

Via a public body.

POLAND

Via a public body.

PORTUGAL

Via a public body.

SLOVAKIA

Via a public body.

SPAIN

Via a public body is the usual route. In Spain the local government gives the permission to open the commercial or industrial activity. The local officer analyses the project of fire safety and sometimes he orders a not compulsory report to Fire Service for more complex problems.

Via a private body is another possible route. In Spain some local governments use outsourcing to delegate the supervision and control of projects of fire safety by authorized private body.

Self-certified. In the future the local government will authorize the project by a "responsible statement" of designer but only for a small project or activity without risk.

UNITED KINGDOM

Via a public body.

Via a private body.

Self-certified.

Question 3.2: Fire brigade in the process

What is the position of the fire brigade in the process?

Answers:

BELGIUM

For public buildings you need a report of the fire brigade before you receive building permission.

CZECH REPUBLIC

Fire protection documentation shall be prepared, managed or supplied to State fire supervision body for approval and control.

If the supplied background or documentation show imperfections with respect to fire safety of buildings, the state fire supervision body stipulates conditions in the approving opinion according to the importance of the imperfections.

FINLAND

The building authority usually consults the relevant fire safety authority (usually employed by the fire brigade) for a statement.

FRANCE

They are consulted at the beginning of the project.

GERMANY

Consultation with the authorities / inspection engineers.

GREECE

Principal role regarding to approval of fire safety design projects, fire inspections etc.

HUNGARY

There are two levels in the legislation. In normal situation just the local Fire Department give the licence. If we need deviation from the code the Civil Defence is the authority having jurisdiction.

ITALY

The fire brigades control and approve the projects and issue the "Certificate of Fire Prevention".

POLAND

Projects must be agreed with a fire expert (fire engineer) appointed after passing the state exam, by the Chief Commandant of the State Fire Service. Before putting building into operation/use it must be checked and officially approved by the fire officer (State Fire Service).

PORTUGAL

Nowadays, due to the responsibility of technicians, is more limited with regard to approval of projects but will continue to play a role in the act of inspections and monitoring.

SLOVAKIA

Fire brigade is responsible for the process of accreditation.

SPAIN

Fire Service has a position only advisory but its reports have an important role in complex projects of fire safety.

UNITED KINGDOM

Statutory consultees to the building control approvals process.

Question 3.3: Third party review

Is a third party review process common?

Answers:

BELGIUM

No.

CZECH REPUBLIC

No.

FINLAND

Third-party review is usually required for FSE design.

FRANCE

No.

GERMANY

No.

GREECE

No.

HUNGARY

No.

ITALY

No.

POLAND

No.

PORTUGAL

No.

SLOVAKIA

I do not know the answer.

SPAIN

No.

UNITED KINGDOM

No.

Question 3.4: Alternative route of approvals for performance-based design

Is it necessary to follow an alternative route of approvals for performance-based design and what would that route be?

Answers:

BELGIUM

Yes via a request for deviation.

Only in the regulations of fire protections in industrial buildings is there a possibility to use performance-based design methods

CZECH REPUBLIC

The legislation has an article that allows engineers to develop projects based on fire safety engineering.

In case of any doubts which scope shall be prepared or managed the fire protection documentation, the decision appertains to the State fire supervision body, which shall decide on the basis of local conditions and after the examination of necessary documents.

FINLAND

No, because all approvals go through the local Building Authority.

FRANCE

No.

GERMANY

No.

GREECE

No.

HUNGARY

This is only possible for buildings to which it is not possible to apply the law. In these cases it is always required the agreement of the OKF The Civil Defence.

ITALY

Yes, the Performance-based Approach may be applied within a Derogation procedure according to the Decree of the Ministry of the Interior 09/05/2007.

POLAND

For new buildings (only) – there is so called "Departure from Regulation": an investor applies to the Ministry of Infrastructure via a local building authority; The Ministry issues the final approval (usually after consultation with the State Fire Service).

Existing buildings - so called „substitute solution": fire expert/fire engineer prepares the expert's technical report of the substitute solution which must be agreed with the Regional Chief Fire Officer of the State Fire Service.

PORTUGAL

The legislation has an article that allows engineers to develop projects based on fire safety engineering. This is only possible for buildings to which it is not possible to apply the law. In these cases it is always required the agreement of ANPC – National Authority of Civil Protection.

SLOVAKIA

Our legislation do not adapt the conditions for possibility of proceed building design. For example engineering access. If there are some buildings do not have respect to prescription of Slovak Republic, they are adapted after consultation with other concrete departments.

SPAIN

In practice the designers use the Prescriptive Rules and only for exceptional projects the Performance-Based Code is allowed but in this case it isn't necessary to use an alternative route.

UNITED KINGDOM

No - functional regulations allow fire engineering as normal part of process.

Question 3.5: Time frame for the approvals process

What is the normal time frame for the approvals process?

Answers:

BELGIUM

Not defined.

CZECH REPUBLIC

Time for obtaining opinion issue:

- 30 days (design of common buildings).

- 60 days (design of specific buildings).

FINLAND

Not defined.

FRANCE

The last fire regulation allows the application of fire safety engineering (performance-based design), but in this case a favourable opinion for the study by a notified body is required. The fire scenarios for a performed based design are defined by local fire safety commissions.

GERMANY

2-6 months.

GREECE

Not defined.

HUNGARY

Not defined.

ITALY

The approval process, according to D.P.R. 37 (12/01/1998), is divided into two phases:

- Project Compliance to technical rules: 45 days from the date of submission;

- Issuance of the Fire Prevention Certificate: After completing works, the owner is required to apply for the certificate; within 90 days from the date of application, the fire brigades have to carry out an inspection to verify the compliance with the design prescriptions;

- Within another 15 days the Fire Prevention Certificate has to be issued.

POLAND

Normal time frame - 1 month. In a complex/complicated 2 months are allowed.

PORTUGAL

Not defined.

SLOVAKIA

The standard time is 30 days.

SPAIN

According to route selected for his approval.

UNITED KINGDOM

Variable dependent on complexity.

Question 3.6: Level of information needed

What level of information must be provided to the approving body?

Answers:

BELGIUM

The project of fire safety of the building.

CZECH REPUBLIC

The project of fire safety of the building.

Preparation of project of fire safety shall be proceeded on the basis of the requirements of specific legislation, normative requirements and requirements of the issued territorial decision.

FINLAND

All relevant information and documentation related to the fire safety of the building.

FRANCE

The project of fire safety of the building.

GERMANY

Detailed information. Fire safety concept and reports of all calculations.

GREECE

The project of fire safety of the building.

HUNGARY

The project of fire safety of the building.

ITALY

The project of fire safety of the building.

POLAND

The expert's technical report must proves that proposed alternative/substitute solution will provide not lower level of safety than prescriptive requirement.

PORTUGAL

The project of fire safety of the building.

SLOVAKIA

The project of fire safety of the building.

SPAIN

The full project of fire safety of the building, with engineering calculations and certificates of applicator of coatings or paints and their laboratory tests.

UNITED KINGDOM

All areas covered by regulations and approved documents.

Question 3.7: Specific facilitators

Are any specific facilitators required to help the engineer in the approvals process?

Answers:

BELGIUM

No.

CZECH REPUBLIC

Yes, Fire rescue service gives support to the designers.

FINLAND

Not defined.

FRANCE

No.

GERMANY

No.

GREECE

Yes, Technical Chamber of Greece could possibly give support to the designers.

HUNGARY

Yes, OKF gives support to the designers.

ITALY

Yes, Italian Fire Brigades give support to the designers.

POLAND

No.

PORTUGAL

Yes, ANPC gives support to the designers.

SLOVAKIA

Do not exist.

SPAIN

Usually the dialogue is open with the local officer.

UNITED KINGDOM

No.

INSURANCE COMPANIES

Question 4.1: Involvement

Are insurance companies involved in the design process?

Answers:

BELGIUM

Indirectly.

Some companies give discount when fire protection systems are foreseen.

Some companies ask for specific fire protection systems.

CZECH REPUBLIC

The insurance companies are involved rarely.

FINLAND

Not necessarily, but their views and conditions may have an influence on the design. It would be recommended to be in touch with the insurance companies at an early stage of the project and include them in the design process if necessary.

FRANCE

No.

GERMANY

Not usually.

GREECE

In most cases not.

HUNGARY

No.

ITALY

In most cases no.

POLAND

In most cases no.

PORTUGAL

In most cases no.

SLOVAKIA

No.

SPAIN

Requirements of insurance companies are more restrictive that the local regulations in important projects, for instance; skyscrapers or industrial installations.

UNITED KINGDOM

In most cases no.

Question 4.2: Discussion with insurance companies

Are insurance companies open to a discussion on fire safety?

Answers:

BELGIUM

Yes.

CZECH REPUBLIC

The insurance companies don´t usually deal with discussion on fire safety. Insurance premium are offered in exceptional cases.

FINLAND

Yes, they usually are.

FRANCE

No.

GERMANY

Often they are conservative.

GREECE

In most cases, insurance companies are not particularly concerned with this matter when establishing insurance premium (except for high risk building categories).

HUNGARY

No.

ITALY

In most cases, insurance companies are not particularly concerned with this matter when establishing insurance premium.

POLAND

In most cases, insurance companies are not particularly concerned with this matter when establishing insurance premium. They usually run routine fire risk assessment. In an opinion of fire authorities it is not satisfactory.

PORTUGAL

In most cases, insurance companies are not particularly concerned with this matter when establishing insurance premium.

SLOVAKIA

At present time are the first steps in this field.

SPAIN

No. Insurance companies only have an important role in arson investigations.

UNITED KINGDOM

In most cases, insurance companies are not particularly concerned with this matter when establishing insurance premium.

QUALIFICATION REQUIREMENTS FOR DESIGNERS

Question 5.1: Certificates/licenses requirements

Is it required to hold specific certificates/licenses in the member state to undertake fire safety design and fire engineering?

Answers:

BELGIUM

Not really but there is a specific master degree:

International Master of Science in Fire Safety Engineering.

CZECH REPUBLIC

The fire safety design and fire engineering are elaborated only by qualified experts (certified technicians or certified engineers) according to Act No. 360/1992 Coll. on the Professional Practice of Certified Architects and on the Professional Practice of Certified Engineers and Technicians Active in Construction.

The conditions for qualification (certification) are required education, working experience and carry out expert test.

FINLAND

Fire safety engineers need to be certified. The certification process is administered by FISE Ltd. (www.fise.fi) and the requirements include:

-   an applicable engineering degree

-   sufficient studies in fire physics and relevant engineering topics

-   a passed exam

-   sufficient work experience in the field.

-   Design based on prescriptive regulation can usually be carried out by practicing structural engineers.

FRANCE

No, is not required a special certificate for the realization of FSE studies, but in fact the number of the persons involved in these studies is very limited. The most of FSE studies in France are realised by notified bodies.

GERMANY

Generally not. In some federal states a license is required.

GREECE

Fire safety design projects are mainly edited by civil engineers (passive fire protection) or mechanical/electrical engineers (active fire protection) according to their professional rights.

HUNGARY

Fire experts need an exam. The Civil Defence give these permit to the fire experts.

ITALY

The designers are required to hold a professional qualification attending the " Specialization Course of Fire Prevention", supported by the Fire Department, according to <u>Law n. 818/1984 and Decree of the Ministry of the Interior, 25/03/1985</u>.

POLAND

Yes, but there are separate licenses for the structural designing and for the assessment of fire protection.

PORTUGAL

In the case of fire safety design for buildings of utilization-type of 3rd and 4th risk category, i.e., for those which have greater complexity, only designers with proven experience by professional association or that have been approved in recognized courses by ANPC can undertake fire safety projects related with the uses mentioned above.

SLOVAKIA

In Slovak Republic is important to have seemly education, specialist preparation and do the exam. After completion of that all conditions the people get the acknowledgment with name "specialist of fire protection, which is limited only for 5 years.

SPAIN

No. In Spain the designer is a person with technical academic formation, such engineer or architect.

In practice, there are professional designers for fire safety projects but not a specific license is necessary.

Otherwise, for a local officer or a referee of private body who revises and approves projects is required a specific licence.

UNITED KINGDOM

Currently there is no requirement.

Question 5.2: Specific design licenses

Are there certain types of buildings for which specific design licenses are required?

Answers:

BELGIUM

No.

CZECH REPUBLIC

No.

FINLAND

Yes, see answer directly above.

FRANCE

Actually, only for smoke evacuation of big volumes is delivered a licence by the Ministry of Interior.

GERMANY

No.

GREECE

No.

HUNGARY

No.

ITALY

There are no specific cases.

POLAND

Yes, regulations specify building types for which a project must be agreed with a fire expert (fire engineer).

PORTUGAL

Yes, for buildings of 3rd and 4th risk category.

SLOVAKIA

The solution of fire safety all buildings solve he specialist of fire protection.

SPAIN

Yes. The level of the licence allows the control of more complex projects of fire safety for local officers or external referees.

Usually, there are two levels: 1 or 2, function of local government of Spain.

UNITED KINGDOM

No.

Question 5.3: Licence holder

Is the licence holder an individual or an organisation?

Answers:

BELGIUM

Not answered

CZECH REPUBLIC

The license holder is individual, but under the auspices of the Czech Chamber of Certified Engineers.

FINLAND

The license holder is an individual.

FRANCE

Organisation.

GERMANY

Individual.

GREECE

The license holder is individual.

HUNGARY

The license holder is organisation.

ITALY

The license holder is individual.

POLAND

The license holder is an individual.

PORTUGAL

The license holder is individual.

SLOVAKIA

The license holder is personal entity.

SPAIN

The license holder is individual (levels 1 or 3).

The private body of control should have an additional licence which has a periodical inspection for its renovation from local government.

UNITED KINGDOM

N/A

Question 5.4 - Specific insurance

Is a specific insurance required?

Answers:

BELGIUM

Not answered

CZECH REPUBLIC

No.

FINLAND

Usually liability insurance is required, or at least recommended.

FRANCE

No.

GERMANY

Not answered

GREECE

No.

HUNGARY

No.

ITALY

No.

POLAND

All licensed structural engineers have to be insured.

For a fire expert (fire engineer) it is not obligatory, this is only a good practice but most are insured.

PORTUGAL

No.

SLOVAKIA

No. If you like it is solved with Standards.

SPAIN

No. The ordinary professional insurance is enough for individual holders.

UNITED KINGDOM

No.

PRECEDENCE OF PERFORMANCE-BASED FIRE ENGINEERING PROJECTS

Question 6.1: Project details

Project details

Answers:

BELGIUM

There were already some PhD projects in the Ghent University, and also the Master thesis's of the first session of the International Master of Science in Fire Safety Engineering.

CZECH REPUBLIC

Fire dynamic analysis and design of construction protection.

FINLAND

Salmisaari Wellness Centre, Helsinki, about 20 000 m^2.

http://www.ruukki.com/References/Sport-arenas-and-terminals/

FRANCE

The temperature of the fire compartment according the adopted fire scenario.

GERMANY

Not answered

GREECE

Not answered

HUNGARY

All the properties of the fire compartment are decided by authority having jurisdiction.

ITALY

The definition of fire scenarios and the temperature of the fire compartment according the adopted fire scenario.

POLAND

Fire scenarios, temperatures in particular compartments, fire duration, final safety certificate.

PORTUGAL

The temperature of the fire compartment according the adopted fire scenario.

SLOVAKIA

Calculation in agreement with Standards.

SPAIN

Smoke control, temperatures and evacuation.

Structural resistance of structure.

Alternative measures of security

UNITED KINGDOM

No specific criteria for the use of fire engineering as an alternative to other methods but usually size and complexity are the main reasons.

Question 6.2: Performance-based

What was performance-based?

Answers:

BELGIUM

N/A

CZECH REPUBLIC

Use various methods of quantitative analyses (deterministic or combined methods), not only in the area of fire protection of buildings.

FINLAND

Structural fire design of steel structures.

FRANCE

The time evacuation of the building, the stability of the building must be ensured throughout all fire, etc...

GERMANY

Not answered

GREECE

Not answered

HUNGARY

The fire scenarios and the structural fire behaviour.

ITALY

The fire scenarios and the structural fire behaviour.

POLAND

Calculation of Required Safe Escape Time or Available Safe Escape Time; selection of fire protection installations in an individual building - based on the assumed scenario of the fire development (computer simulations - fire models); defining parameters of fire protection installations (e.g. smoke control systems).

The fire scenarios and the structural fire behaviour.

PORTUGAL

The fire scenarios and the structural fire behaviour.

SLOVAKIA

Calculations.

SPAIN

The fire scenarios

UNITED KINGDOM

Tenability for life safety, means of escape and structural stability are the main performance criteria.

Question 6.3: Used techniques

What techniques are used to justify the non-compliance?

Answers:

BELGIUM

N/A

CZECH REPUBLIC

In technical standards is defined generally that in these techniques are buildings with extraordinary risk or special risk character in term of fire safety.

FINLAND

FDS simulations based on statistical data on fire loads in different premises. The cooling effect of sprinklers was partly accepted.

FRANCE

The difficulties to applied the prescriptive rules.

GERMANY

Not answered

GREECE

Not answered

HUNGARY

If the regulation, due to the big dimension in plan and height of the building, is not adequate to be adopted, the building can be classified as "atypical danger" and fire safety engineering can be used.

ITALY

The regulations are basically prescriptive and concern several types of building use (DM 12/02/1982).

The performance-based design and advanced calculation methods may be applied either in the lack of prescriptive rules or in the case of "derogation" with respect to prescriptive rules. The performance-based design has to developed according to D.M. 09/05/2007.

POLAND

Calculations, an individual assessment, agreements with local fire brigade authorities; a new project on creation of the supporting system for all fire brigades (State Fire Service) has been implemented (special IT tools allowing simple exchange of digital data).

PORTUGAL

If the regulation, due to the big dimension in plan and height of the building, is not adequate to be adopted, the building can be classified as "atypical danger" and fire safety engineering can be used.

SLOVAKIA

If it is in conflict with legal prescriptions.

SPAIN

Fire dynamic analysis techniques and advanced calculation models.

UNITED KINGDOM

Fire engineering is used along with code-based methods – no specific reasons or techniques required before it can be employed.

Question 6.4: Approvals route

What approvals route was used?

Answers:

BELGIUM

N/A

CZECH REPUBLIC

The fire safety project must be approved by Fire rescue service.

FINLAND

Local building and fire authorities together with responsible Fire Consultant, structural designer and steel structure manufacturer. The main simulation was done together with research institutes, VTT, TUT.

FRANCE

The fire safety project must be approved by local fire safety commission.

GERMANY

Not answered

GREECE

Not answered

HUNGARY

The fire safety project must be approved by Civil Defence.

ITALY

The fire safety project must be approved by Regional Fire Brigades.

POLAND

The fire safety project must be approved by entitled fire officer or (depending on a type of building) by Authority of Fire Brigade.

PORTUGAL

The fire safety project must be approved by ANPC – National Authority of Civil Protection.

SLOVAKIA

The accreditation is done by the Fire Brigade of Slovak Republic.

SPAIN

Ordinary route in local government.

UNITED KINGDOM

Usual route through functional building regulations.

PASSIVE FIRE PROTECTION

Question 7.1: Product approvals

What are the possible product approvals of fire protection materials and methods (National, ETA or CE marking)?

Answers:

BELGIUM

National: BENOR ATG

ETA

CE marking.

CZECH REPUBLIC

Namely CE marking.

FINLAND

CE marking / ETA for cases where Eurocodes are used

National product approvals for cases where the National Building Code is used for design / CE-marking or ETAs can sometimes also be used in this case.

FRANCE

CE marking.

GERMANY

National ü-marking or European CE-marking.

GREECE

CE marking.

HUNGARY

CE marking.

ITALY

CE marking.

POLAND

European Certification Process (CE marking)- with requirements of the EU harmonized standards. This procedure is required to issue a declaration of conformity with CPD (construction products) or PPE (personal protective equipment) directives by manufacturer – obligatory for all products used for fire protection.

National:

Regulation of the Minister of Interior and Administration dated 20th of June, 2007 regarding the list of products which ensure public safety or health care and life protection or property protection and

concerning the rules of issue the certificate of admittance for these products to use (O. J. No. 143 pos. 1002),

With requirements of Polish Standards, national technical approvals - this procedure is required to issue the national declaration of conformity and mark products with construction marking by its manufacturer.

PORTUGAL

CE marking.

SLOVAKIA

Certificate.

SPAIN

At the moment, the CE marking is not mandatory in Spain. The national standards tests in Spanish laboratories are required to certificate the fire protection materials and its application.

Nevertheless, there are several protocols for semiautomatic certification of products by the inter-laboratories European network.

After an extended period of transition, there are previsions of more two years for the mandatory CE marking in Spain

UNITED KINGDOM

National and CE marking

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