Comprehensive fire protection and safety with concrete

BCA British Cement Association

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BRITISH READY-MIXED CONCRETE ASSOCIATION

the Sign of Quality

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Comprehensive fire protection and safety with concrete

This document was produced by CEMBUREAU, BIBM and ERMCO. Aimed at specifiers, regulators, building owners, fire authorities, insurance companies and the general public, it shows how concrete can be used to provide comprehensive fire protection including life safety, protection of property and of the environment.

Contents

Lives and property are protected with concrete

1. CONCRETE PROVIDES COMPREHENSIVE FIRE PROTECTION

Concrete's excellent and proven fire resistance properties deliver protection of life, property and the environment in the case of fire. It responds effectively to all of the protective aims set out in European legislation, benefiting everyone from building users, owners, businesses and residents to insurers, regulators and firefighters. **Whether it is used for residential buildings, industrial warehouses or tunnels, concrete can be designed and specified to remain robust in even the most extreme fire situations.**

Everyday examples and international statistics provide ample evidence of concrete's fire protecting properties, and so building owners, insurers and regulators are making concrete the material of choice, increasingly requiring its use over other construction materials. By specifying concrete, you can be sure you have made the right choice because it does not add to the fire load, provides fire-shielded means of escape, stops fire spreading between compartments and delays any structural collapse, in most cases preventing total collapse. **In comparison with other common construction materials, concrete offers superior performance on all relevant fire safety criteria, easily and economically**.

Using concrete in buildings and structures offers exceptional levels of protection and safety in fire:

- Concrete does not burn, and does not add to the fire load
- Concrete has high resistance to fire, and stops fire spreading
- Concrete is an effective fire shield, providing safe means of escape for occupants and protection for firefighters
- Concrete does not produce any smoke or toxic gases, so helps reduce the risk to occupants
- Concrete does not drip molten particles, which can spread the fire
- Concrete restricts a fire, and so reduces the risk of environmental pollution
- Concrete provides built-in fire protection – there is normally no need for additional measures
- Concrete can resist extreme fire conditions, making it ideal for storage premises with a high fire load
- Concrete's robustness in fire facilitates firefighting and reduces the risk of structural collapse
- Concrete is easy to repair after a fire, and so helps businesses recover sooner
- Concrete is not affected by the water used to quench a fire
- Concrete pavements stand up to the extreme fire conditions encountered in tunnels.

It's a simple choice to make – one that has far reaching effects

A comprehensive approach

Reducing deaths in fire and the impact of fire damage requires a comprehensive approach to fire safety. In 1999, the World Fire Statistics Centre presented to UN Task Group for Housing a report compiling international data on building fires (Neck, 2002). The study of 16 industrialised nations found that, in a typical year, the number of people killed by fires was 1 to 2 persons per 100,000 inhabitants and the total cost of fire damage amounted to 0.2 to 0.3% of gross national product (GNP), see Table 5.1.

We have to be prepared for the possible outbreak of fire in most buildings, and its effects on both lives and livelihoods. The aim is to ensure that buildings and structures are capable of protecting both people and property against the hazards of fires. Although fire safety codes are written with both these aims in mind, understandably it is the safety of people that often assumes the greater importance. But private owners, insurance companies and national authorities may also have interests in fire safety for other reasons, such as **economic survival, data storage, environmental protection and upkeep of critical infrastructure**. All of these factors are taken into account in European and national legislation on fire safety, see Figure 1.1.

Structural fire protection measures must fulfil three aims:

- **Personal protection** to preserve life and health;

- **Protection of property** to preserve goods and other belongings both in residential or commercial units that have caught fire, and in neighbouring properties. To this must be added substantial preservation of the building structures;
- **Environmental protection** to minimise the adverse effects on the environment through smoke and toxic gases as well as from contaminated water used for extinguishing fires.

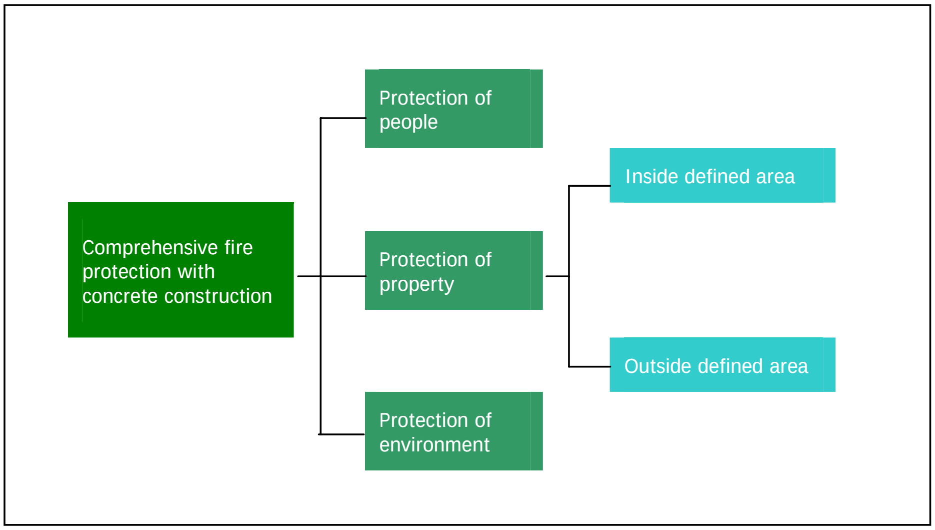


Figure 1.1: The comprehensive approach to fire safety (*Courtesy Neck, 2002*)

With concrete construction all three aims can be achieved. Its non-combustibility and high fire resistance mean that concrete provides comprehensive fire protection for **people, property and the environment.**

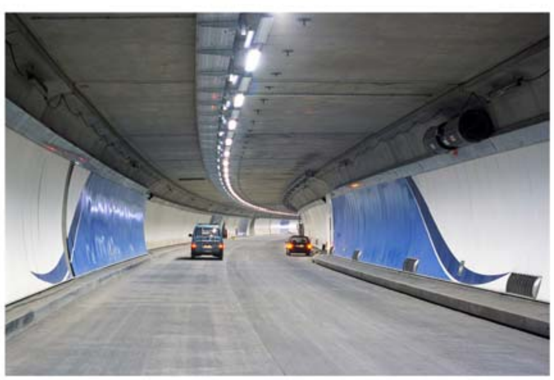
Concrete's natural fire resistance properties are compared with other building materials in Table 1.1, which shows how concrete scores against a range of key properties.

Table 1.1: Summary of unprotected construction materials performance in fire

Unprotected construction material	Fire resistance	Combustibility	Contribution to fire load	Rate of temperature rise across a section	Built-in fire protection	Repairability after fire	Protection for evacuees and fire-fighters
Timber	Low	High	High	Very low	Very low	Nil	Low
Steel	Very low	Nil	Nil	Very high	Low	Low	Low
Concrete	High	Nil	Nil	Low	High	High	High

Figure 1.2:
In this warehouse fire in France, the firefighters were able to shelter behind the concrete wall in order to approach the fire closely enough to extinguish the flames. (*Courtesy DMB/Fire Press – Revue soldats du feu magazine, France)*

Figure 1.3:
The North Galaxy Towers in Brussels. This reinforced concrete 30-storey concrete building meets the current strict requirements for fire resistance (REI 120); the columns are of high-strength C80/95 concrete. *(Courtesy ERGON, Belgium*)



Cointe tunnel (link E25-E40) in Liege, Belgium: use of concrete road pavement for improved tunnel safety

Figure 1.4:
Concrete tunnels and road surfaces will stand up to the extreme fire conditions encountered in tunnels.

Concrete does not burn, produce smoke or emit toxic gases. It also provides protection against the spread of fire

2. CONCRETE'S PERFORMANCE IN FIRE

There are two key components to concrete's successful performance in fire: first its basic properties as a building material and secondly, its functionality in a structure. Concrete is non-combustible (it does not burn) and it has a low rate of temperature rise across a section (it is fire shielding), which means that in most structures concrete can be used without any additional fire protection. Many of concrete's fire resisting properties are consistent no matter whether it is structurally normal or lightweight, or produced as concrete masonry or autoclaved aerated concrete. In essence, no other material can make such a comprehensive case for its fire safety performance (see Table 1.1).

Concrete does not burn

Concrete simply cannot be set on fire like some other materials in a building. It is resistant to smouldering materials, which can reach very high temperatures, igniting or even re-igniting a fire, and flames from burning contents cannot ignite concrete. So, because it does not burn, concrete does not emit any smoke, gases or toxic fumes when affected by fire. It will also not drip molten particles, which can cause ignition, unlike some plastics and metals. **There is no way in which concrete can contribute to the breakout and spread of fire or add to the fire load**.

Authoritative evidence of concrete's fire performance properties is presented in European standards. All building materials have been classified in terms of their reaction to fire and their resistance to fire, which will determine whether or not a material can be used and when additional fire protection needs to be applied to it. Based on the European Construction Products Directive, EN 13501–1: 2002: *Fire classification of construction products and building elements* classifies materials into seven grades with the designations, A1, A2, B, C, D, E and F, according to their reaction to fire.

The highest possible designation is A1 (non-combustible materials) and the European Commission has published a binding list of approved materials for this classification, which includes the various types of concrete and also the mineral constituent materials of concrete. **Concrete fulfils the requirements of class A1 because its mineral constituents are effectively non-combustible** (i.e. do not ignite at the temperatures that normally occur in fire).

Concrete is a protective material

Concrete has a high degree of fire resistance and, in the majority of applications, can be described as fireproof when properly designed. Concrete is a very effective fire shield. The mass of concrete confers a high heat storage capacity. Also its porous structure provides a low rate of temperature rise across a section. These properties result in a low rate of temperature rise that enables concrete to act as an effective fire shield.

Due to the low rate of increase of temperature through the cross section of a concrete element, internal zones do not reach the same high temperatures as a surface exposed to flames. The standard ISO 834 fire test on 160 mm wide x 300 mm deep concrete beams exposed three sides to fire for one hour. While a temperature of 600°C was reached at 16 mm from the surface, this was halved to just 300°C at 42 mm from the surface – a temperature gradient of 300°C in just 26 mm of concrete! (Kordina, Meyer-Ottens, 1981). This shows clearly how concrete's relatively low rate of increase of temperature ensures that its internal zones remain well protected.

Even after a prolonged period, the internal temperature of concrete remains relatively low; this enables it to retain structural capacity and fire shielding properties as **a separating element**.

When concrete is exposed to the high temperatures of a fire, a number of physical and chemical changes can take place. These changes are shown in Figure 2.1, which relates temperature levels within the concrete (not the flame temperatures) to changes in its properties.

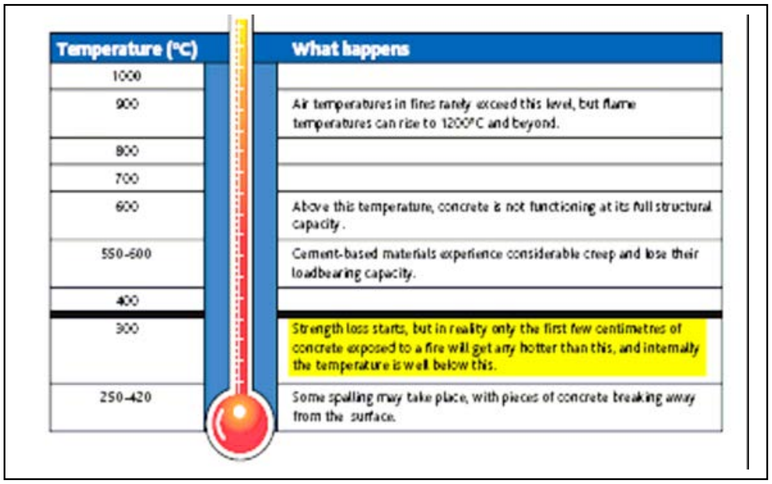


Figure 2.1: Concrete in fire: physical processes. *(Khoury 2000)*

Spalling

Spalling is part of concrete's normal response to the high temperatures experienced in a fire. Therefore, for normal buildings and normal fires (e.g. offices, schools, hospitals, residential), the design codes like Eurocode 2 already include the effect of spalling for these applications. The fact that concrete does spall in a fire is implicit in design codes, with the exception of tunnels or hydrocarbon fires (which are discussed in Section 4 – Protecting people). For example, research on the experimental results used as the basis for developing the UK structural concrete design code (BS 8110) found that these supported the assumed periods of fire resistance and in many cases were very conservative (Lennon, 2004). Figure 2.2 shows a comparison between floor slab performance in fire tests and their assumed performance within
BS 8110. Many of the specimens experienced spalling during the fire tests, so the fact that most slabs exceeded assumed levels of performance is clear evidence that spalling is both accounted for in design codes and does not seriously affect concrete's fire resistance in everyday fires.

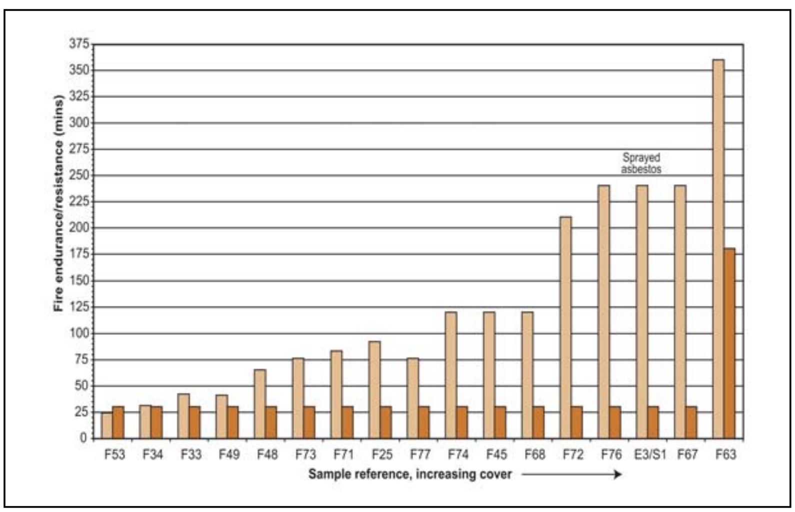


Figure 2.2: Comparison between measured (buff) and assumed (orange) fire resistance, based on depth of cover. *(From Lennon 2004)*

Concrete provides effective compartmentation

Concrete protects against all the harmful effects of a fire and has proved so reliable that it is commonly used to provide stable compartmentation in large industrial and multi-storey buildings. By dividing these large buildings into compartments, the risk of total loss in the event of a fire is virtually removed – the concrete floors and walls reduce the fire area both horizontally (through walls) and vertically (through floors). Concrete thus provides the opportunity to install safe separating structures in an easy and economic manner; its fire shielding properties are inherent and do not require any additional fire stopping materials or maintenance.

Figure 2.3
Precast walls form fire resistant compartmentation for this storage facility. *(Courtesy BDV, Germany)*

Concrete is easier to repair after a fire

The majority of concrete structures are not destroyed in a fire, and so one of the major advantages of concrete is that it can usually be easily repaired afterwards, thereby minimising any inconvenience and cost. The modest floor loads and relatively low temperatures experienced in most building fires mean that the loadbearing capacity of concrete is largely retained both during and after a fire. For these reasons often all that is required is a simple clean up. Speed of repair and rehabilitation is an important factor in minimising any loss of business after a major fire; it is obviously preferable to demolition and reinstatement.

CASE STUDY 1

Fire in a high-rise building in Frankfurt, Germany (1973)

In the night of 22 August 1973 a severe fire broke out on the 40th floor of the first high-rise building in Frankfurt. The fire rapidly spread to the 38th and 41st floor, the top floor of this twin block, 140m high office building. The entire vertical and horizontal load-bearing structure of this building was made of reinforced concrete with a double-T shaped flooring system.

Because the riser pipes had not been correctly connected, the firefighting could only begin two hours after the fire had started. Three hours later the fire was under control. In all it took about eight hours for the fire to be extinguished (Beese, Kürkchübasche, 1975).

All the structural elements withstood the fire although they were exposed to the flames for some four hours. In many places the concrete spalled and in several cases the reinforcement was not only visible, but also fully exposed. Fortunately the structure did not fail during the fire and afterwards it was not necessary to demolish entire storeys – a hazardous job at a height of more than 100 m above the ground. It was possible to repair most of the elements on site by reusing and strengthening the reinforcement and by concrete guniting.

The ease of recovery of this building after the fire is a typical example of the high fire resistance of concrete structures and of the way it is possible to repair the structure in a safe manner.

Figure CS1.1:
Frankfurt building fire
(Courtesy DBV, Germany)

Figure CS1.2
Example of concrete elements after the fire showing spalling.
(Courtesy DBV, Germany)

Figure CS1.3
Repairing elements with guniting (sprayed concrete)
(Courtesy DBV, Germany)

Concrete structures easily meet all national and European fire requirements

3. DESIGN FOR FIRE SAFETY WITH CONCRETE

Proper design and choice of materials are crucial to ensuring fire safety. This section explains the main design considerations with respect to fire.

Designing fire-safe buildings

Previously, fire-safety requirements were provided by national governments, but they are now based on European directives, standards and guidelines. There are four principal objectives that have to be fulfilled when designing a building to be fire safe. Concrete can satisfy all the objectives of fire safety with ease, economy and with a high degree of reliability. The main requirements are shown in Figure 3.1, and Table 3.1 shows some examples of how the requirements can be met using concrete construction and demonstrates the comprehensive protective functions of concrete structures.

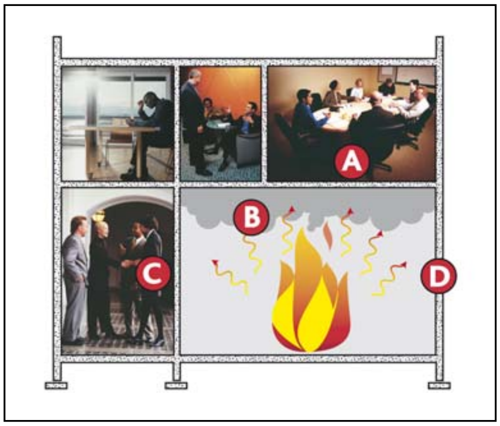


Figure 3.1
The structure should:
A – retain its loadbearing capacity
B – protect people from harmful smoke and gases
C – shield people from heat
D – facilitate intervention by firefighters
(Courtesy The Concrete Centre, UK)

Figure 3.2:
Protection provided by concrete construction – see D in Figure 3.1 above. *(DMB/Fire Press – Revue soldats du feu magazine, France)*

The five requirements in Table 3.1 must be taken into account when designing a structure, and this is the foundation for design methods for structural elements in respect of fire safety in the Eurocodes (e.g. EN 1992–1–2 (Eurocode 2) *Design of concrete structures – Structural fire design*).

Table 3.1: Requirements for fire safety and their relation to concrete

Objective	Requirement	Use of concrete
1. To **reduce the development** of a fire	Walls, floors and ceilings should be made of a non-combustible material	Concrete as a material is inert and **non-combustible** (class A1);
2. To ensure **stability** of the loadbearing construction elements over a specified period of time	Elements should be made of non-combustible material and have a high fire resistance.	Concrete is non-combustible and due to its low thermal conductivity most of its **strength is retained** in a typical fire.
3. To limit the generation and **spread** of fire and smoke	Fire separating walls and floors should be non-combustible and have a high fire resistance.	In addition to the above, adequately designed connections using concrete **reduce the vulnerability to fire** and make full use of its structural continuity.
4. To assist the **evacuation** of occupants and ensure the safety of rescue teams	Escape routes should be made of non-combustible material and have a high fire resistance, so they can be used without danger for a longer period.	Concrete cores are **extremely robust** and can provide very high levels of resistance. Slipforming or jumpforming are particularly effective methods of construction.
5. To facilitate the **intervention** of rescue parties (firefighters)	Loadbearing elements should have a high fire resistance to enable effective firefighting; there should be no burning droplets.	Loadbearing elements **retain their integrity** for a long time and concrete will not produce any molten material.

The following fire protection criteria must be met by any construction designed to Eurocode 2: Resistance (R), Separation (E) and Isolation (I). These three criteria are explained in Table 3.2. The designation letters R, E and I are used together with numbers referring to the resistance in minutes against the ISO standard fire. So, a loadbearing wall resistant to fire for 90 minutes would be classified as **R90**; a loadbearing, separating wall would be **RE 90;** and a loadbearing, separating, fire-shielding wall would be **REI 90.**

Table 3.2: The three main fire protection criteria, adapted from Eurocode 2, Part 1–2.

Designation	Fire limit state	Criterion
Résistance (R) <u>Also called:</u> Fire resistance Loadbearing capacity	**Limit of load** The structure should retain its loadbearing capacity	The loadbearing resistance of the construction must be guaranteed for a specified period of time *The time during which an element's fire resisting loadbearing capability is maintained, which is determined by mechanical strength under load*
Etanchéité (E) <u>Also called:</u> Flame arresting Separation, Tightness	**Limit of integrity** The structure should protect people and goods from flames, harmful smoke and hot gases	There is no integrity failure, thus preventing the passage of flames and hot gases to the unexposed side *The time during which, in addition to fire resistance, an element's fire separation capability is maintained, which is determined by its connections tightness to flames and gases*
Isolation (I) <u>Also called:</u> Fire shielding Heat screening Separation	**Limit of insulation** The structure should shield people and goods from heat	There is no insulation failure, thus restricting the rise of temperature on the unexposed side *The time during which, in addition to both fire resistance and fire separation, an element's fire shielding capability is maintained, which is defined by a permissible rise in temperature on the non-exposed side*
Each of the above limit states is expressed in minutes, at intervals as follows: 15, 20, 30, 45, 60, 90, 120, 180, 240, 360.		

Note that the letters R, E, I are derived from the French terms; they remain so in the Eurocode in recognition of the fact that they were first introduced in France.

CASE STUDY 2

Fire tests on a full-scale concrete building frame

Concrete's properties in respect of the R, E and I criteria were put to the test when a full-scale fire experiment (see Figure CS2.1) was carried out on the concrete test building at the independently-run Building Research Establishment (BRE) in Cardington, England in 2001 (Chana and Price, 2003). The results from the test were summarised by the BRE, as follows.

> *"The test demonstrated excellent performance by a building designed to the limits of Eurocode 2. The building satisfied the performance criteria of load bearing, insulation and integrity when subjected to a natural fire and imposed loads. The floor has continued to support the loads without any post fire remedial action being carried out."*

Figure CS2.1
Fire test on concrete frame at BRE
(Courtesy Building Research Establishment, UK)

Using Eurocode 2

Eurocode 2 Part 1–2, *Structural fire design* covers fire safety design using concrete structures, including coverage of accidental fire exposure, aspects of passive fire protection and general fire safety, as categorised by the R, E, I criteria explained previously.

As shown in Figure 3.3, EC2 enables engineers to dimension a structure and verify its fire resistance using one of the three methods, by using one of three methods:

1. Determining the minimum cross-sectional values of both dimensions and concrete cover in accordance with **tables**.
2. Dimensioning the element's cross-section, with a **simplified method** for establishing the remaining, undamaged cross-section as a function of the ISO temperature curve.
3. Dimensioning with **general methods of calculation** as a function of temperature stress and the behaviour of the element under heating.

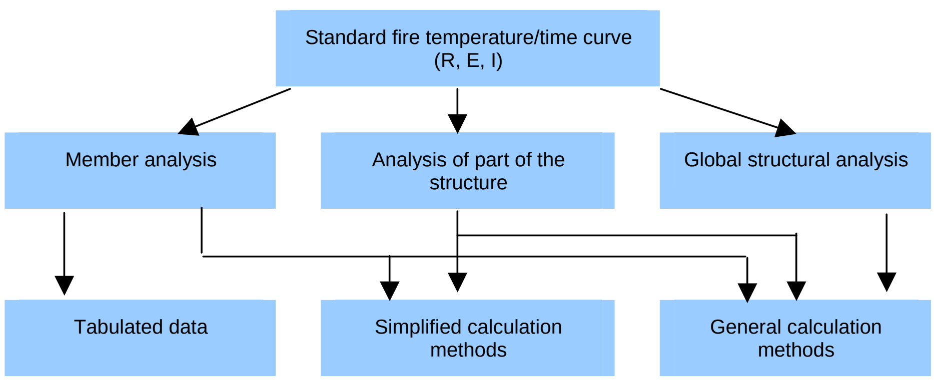


Figure 3.3: Design procedure for fire resistance of structures

In addition to the generic clauses on fire design, which are applicable throughout Europe, EU member states are free to fix values for some important parameters or procedures in their National Annex Documents (NADS). It is important that designers consult these NADS to ensure they are following the correct approach for the country in which they are working or producing a design for. Advisory documents such as Naryanan and Goodchild (2006), which focus on UK design, will act as useful reference works for designers wishing to update or improve their understanding of Eurocode 2. Denoel/Febelcem's (2006) comprehensive guide to fire safety design with concrete is also useful and includes extensive coverage of the various design methods within the Eurocodes.

Concrete protects life and enhances safety of both occupants and firefighters

4. PROTECTING PEOPLE

Very often fire threatens human life. This fact drives improvements in fire safety and compels us to design buildings that are capable of protecting people and their property against the hazards of fires. Concrete buildings and structures give personal protection against fire to preserve both life and health, in accordance with the European legislation on fire safety. Section 2 of this publication explained how concrete behaves in fire, and how its material properties function effectively in terms of fire resistance.

Life protection relies on concrete's inherent robustness, its non-combustibility and heat shielding properties to ensure that buildings remain stable during fire. This enables people to survive and escape, it allows firefighters to work safely and, what's more, it reduces the environmental impact caused by combustion products – this section explains how.

Concrete structures remain stable during fire

In fire-safety design, the functions of a structural element can be designated as loadbearing, separating, and/or fireshielding (R, E, I) and are typically given a numerical value (in minutes, from 15 to 360) which is the duration for which the element can be expected to perform those functions (see Section 3 for an explanation). In the event of a fire, the structure must perform at least to the level required by legislation, but additionally, maintaining the stability of the structure for as long as possible is obviously desirable for survival, escape and firefighting. This is particularly important in larger complexes and multi-storey buildings. Structural frames made of concrete are designed to satisfy this demand for overall stability in the event of a fire and in many cases will exceed expectations. The non-combustibility and low level of temperature rise of concrete mean concrete will not burn and its strength will not be affected significantly in a typical building fire. Furthermore, concrete's inherent fire resistance acts as long-lasting, passive protection – concrete is the only construction material that does not have to rely on active firefighting measures such as sprinklers for its fire performance.

The protection provided by concrete is clearly shown by the behaviour of the Windsor Tower in Madrid during a catastrophic fire in February 2005. The concrete columns and cores prevented the 29-storey building from collapsing, and the strong concrete transfer beams above the 16th floor contained the fire above that level for seven hours, as can be seen in Case Study 3.

Case Study 3

The Windsor Tower, Madrid, Spain (2005)

This 122 million Euro fire during the refurbishment of a major multi-storey office building in Madrid's financial district provides an excellent example of how traditional concrete frames perform in fire. Built between 1974 and 1978, the Windsor tower consisted of 29 office storeys, five basement levels and two 'technical floors' above the 3rd and 16th floors. At the time of its design, sprinklers were not required in Spain's building codes, but this was subsequently amended and hence the tower was being refurbished to bring it into line with current regulations. The scope of the work included fireproofing all the steel perimeter columns, adding a new façade, new external escape stairs, alarm and detection upgrades, plus the addition of two further storeys. At the time of the fire, an international accountancy company occupied 20 floors of the building and two storeys were given over to a Spanish law firm. The shape of the building was essentially rectangular, measuring 40 m x 26 m from the 3rd floor and above. The structural frame used normal strength concrete in its central core, columns and waffle slab floors; much of the façade featured concrete perimeter columns, but the most important feature of the tower was to be its two concrete 'technical floors'. These two 'technical' or strong floors, each with eight super-deep concrete beams (measuring 3.75 m in depth; the floor to ceiling height elsewhere), were designed to act as massive transfer beams, preventing progressive collapse caused by structural elements falling from above.

The fire broke out late at night, almost two years after the start of the refurbishment; the building was unoccupied. It started on the 21st floor and spread quickly; fire spread upwards through openings made during the refurbishment and via the façade (between perimeter columns and the steel/glass façade), and downwards via burning façade debris entering windows below. The height, extent and intensity of the blaze meant firefighters could only try to contain it and protect adjacent properties, so the fire raged for 26 hours, engulfing almost all the floors (see Figure CS3.2).

When the fire was finally extinguished, the building was burnt out completely above the 5th floor, much of the façade was destroyed and there were fears that it would collapse. However, throughout the fire and until eventual demolition, the structure remained standing; only the façade and floors above the upper concrete 'technical floor' suffered collapse. The passive resistance of the concrete columns and core had helped prevent total collapse, but the role of the two concrete 'technical floors' was critical, particular the one above the 16th storey, which contained the fire for more than seven hours. It was only then, after a major collapse, that falling debris caused fire to spread to the floors below this, which burned, but again damage was limited to the storeys above the lower 'technical floor' at the 3rd level.

This is powerful evidence that strong, concrete floors at regular intervals can minimise the risk of collapse and prevent the spread of fire. The only forensic report on the Windsor building's fire performance was carried out by Spanish researchers from the Instituto Técnico de Materiales y Construcciones (Intemac). This independent investigation focused on the fire resistance and residual bearing capacity of the structure after the fire (Intemac, 2005). Amongst Intemac's findings, the 2005 report states that:

"The Windsor building concrete structure performed extraordinarily well in a severe fire and clearly much better than would have been expected had the existing legislation for concrete structures been strictly applied. The need for due fireproofing of the steel members to guarantee their performance in the event of a fire was reconfirmed. Given the performance of these members on the storeys that had been fireproofed, it is highly plausible, although it can obviously not be asserted with absolute certainty, that if the fire had broken out after the structure on the upper storeys had been fireproofed, they would not have collapsed and the accident would very likely [have] wreaked substantially less destruction".

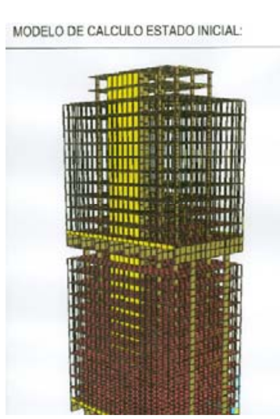


Figure CS3.1 Above
The fire rages in the Windsor Tower, Madrid. *(Courtesy IECA, Spain)*

Figure CS3.2 Top left
The façade above the technical floor at level 16 was totally destroyed. *(Courtesy IECA, Spain)*

Figure CS3.3 Left
Plan showing the position of the technical floor. *(Courtesy OTEP and CONSTRUCCIONES ORTIZ, Spain)*

The Spanish research centre Instituto de Ciencias de la Construcción Eduardo Torroja (IETcc) in collaboration with the Spanish Institute of Cement and its Applications (IECA), investigated the reinforced concrete structural elements of the Windsor Tower. The research included a microstructural study on these elements using thermic analysis and an electronic microscope. It was observed that the temperature reached inside the concrete was 500 ºC at a distance of 5 cm from the surface subjected to fire. This result confirms the severity of the Windsor Tower fire and the good performance of concrete cover complying with the design standards for fire safety of concrete structures.

Concrete provides a safe escape and safe firefighting

The fact that concrete structures remain stable in fire is of particular relevance to the safe evacuation of occupants in a building and firefighting activities. Concrete stairwells, floors, ceilings and walls prevent the spread of fire and act as robust compartments, thereby providing safe means of escape and access for rescue teams. Concrete escape routes have a degree of robustness and integrity not seen in other construction materials, whether it is used for residential buildings or crowded places like shopping centres, theatres and office towers. Using concrete also means that the safety of firefighters is not compromised. Loadbearing and space-enclosing building components made of concrete offer effective protection to firefighters even when inside a burning building. Only under these conditions can such activities be carried out with a reduced risk. The recommendations issued by the National Institute of Standards and Technology (NIST) following the collapse of the World Trade Centre are very relevant, see Case study 4.

At the opposite end of the spectrum to high-rise towers are tunnels, and here concrete also has a vital role to play in saving lives – see Case Study 5

Case study 4

World Trade Centre Buildings, New York (2001)

Without doubt, the National Institute of Standards and Technology (NIST) investigation following the World Trade Centre disaster in New York in September 2001 is one of the most significant and influential reports ever written on safety in buildings (see http://wtc.nist.gov/ for further information). The final set of reports, totalling 10,000 pages, was published in 2006 following a three-year fire and building and fire safety investigation into what has been described as the worst building disaster in history, in which more than 2,800 people were killed. The majority of these people were alive at the time the two buildings collapsed. NIST studied the factors leading to the probable causes for the collapse of the two steel-framed office towers and were able to make some 30 recommendations on codes, standards and practices in the areas of structural design and life safety. Among its many recommendations, the NIST report calls for:

- **Increased structural integrity**; including prevention of progressive collapse and adoption of nationally accepted testing standards.
- **Enhanced fire resistance of structures**; the need for timely access and evacuation, burnout without partial collapse, redundancy in fire protection systems, compartmentation, and the ability to withstand maximum credible fire scenario without collapse.
- **New methods for fire resistance design of structures**: including the requirement that uncontrolled building fires should burn out without partial or total collapse.
- **Improved building evacuation**: to maintain integrity and survivability.
- **Improved active fire protection**: alarm, communication and suppression systems.
- **Improved emergency response technologies and procedures**.
- **Tightening up regulations on sprinklers and escape routes in existing buildings**

Dr Shyam Sunder, who led the investigation on behalf of NIST, has acknowledged the exceptional circumstances which eventually lead to the towers' collapse, but explains that the NIST team were able to make a number of top priority, realistic, appropriate and achievable, performance-oriented recommendations as a result of the analysis and testing that was carried out. Concrete is able to meet these recommendations with ease.

Further to this, the American Society of Civil Engineers (ASCE) building performance report on the airplane impact to the Pentagon building, which was attacked at the same time, concluded that the reinforced concrete structure had been influential in preventing further damage to the building (ASCE, 2003). It states that the "continuity, redundancy and resiliency within the structure contributed to the building's performance" and recommended that such features be incorporated into buildings in the future, particularly where risk of progressive collapse is deemed important.

Case study 5

Improving fire safety in road tunnels

Europe is served by over 15,000 kilometres of road and rail tunnels; these are part of our transport infrastructure and are particularly important in mountainous regions, but increasingly so in major cities where tunnels can relieve traffic congestion and free up urban spaces. The problem is that accidents involving vehicles can cause extremely severe fires; tunnel fires tend to reach very high temperatures due to the burning fuel and vehicles, reportedly up to 1350 ^{o}C, but more usually around 1000 – 1200^{o}C. Peak temperatures are reached more quickly in tunnels compared with building fires, mainly because of the hydrocarbons in petrol and diesel fuel, but also because of the confined spaces (see Figure CS6.1).

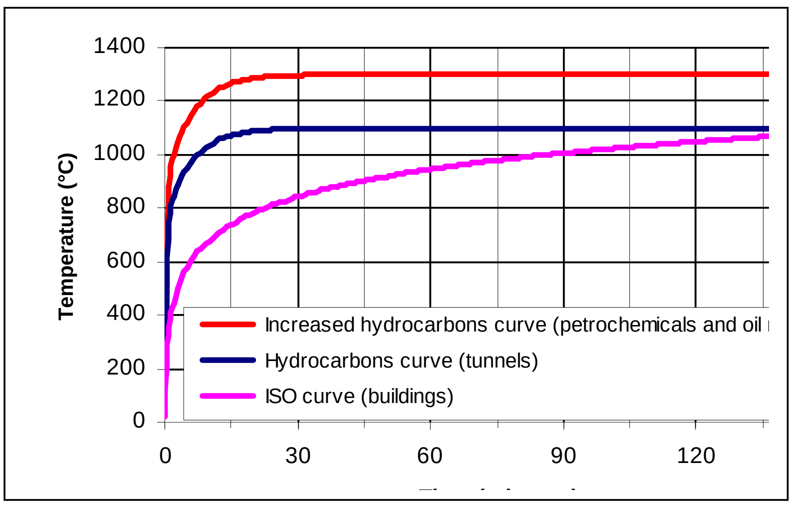


Figure CS5.1:
Tunnel fires burn at very high temperatures. *(Courtesy J-F Denoel/FEBELCEM, Belgium)*

Munich Reinsurance Group (2003) reports that fire is 20 times more likely to break out in a road tunnel than in a railway tunnel and these extreme fires are often fatal; when exposed to smoke, human life expectancy has been estimated at less than two minutes because the gases produced can be so highly toxic. Furthermore, fires in lengthy tunnels in remote areas can burn for a very long time: the Mont Blanc tunnel fire in 2001 burned for an astonishing 53 hours. Indeed, major incidents, such as those in the Channel Tunnel (1996), Mont Blanc (1999) and St Gotthard (2001), have publicised the devastating consequences of tunnel fires and highlighted the shortcomings of the construction materials and structural solutions involved. As a result, the regulators' focus has been on improving conditions for evacuation and rescue of people involved in accidents in road tunnels, with specifiers now concentrating on safety, robustness and stability.

Neither, however, has perhaps paid sufficient attention to the road construction material and its contribution to the fire load; thus, there is a need to take a more holistic approach to tunnel design and construction by considering a concrete solution (CEMBUREAU, 2004). In the case of fire in road tunnels, an incombustible and non-toxic road pavement like concrete contributes to the safety of both vehicle occupants and rescue teams. Concrete fulfils both these criteria because it is incombustible (does not burn), does not add to the fire load, does not soften (hence, does not hinder firefighters), distort or drip, and does not emit harmful gases in a fire, no matter how severe. Concrete can be used as a tunnel lining on its own or with a thermal barrier, but it can also be used for the road pavement. This is particularly useful because it can replace asphalt. Compared with asphalt, concrete means:

- **Improved safety**: concrete does not burn and does not give off harmful gases (asphalt ignites at around 400 to 500°C and within a few minutes emits suffocating, carcinogenic vapours, smoke, soot and pollutants). In the Mont Blanc fire, 1200 m of the asphalt pavement burned with a ferocity equivalent to an additional 85 cars being alight (CEMBUREAU, 2004).
- **Better durability** of the pavement, facilities and structure: concrete does not change shape as it heats up, whereas asphalt ignites, loses its physical shape and hinders evacuation and rescue.
- **Extended maintenance intervals** compared with an asphalt pavement
- **Better lighting**; concrete is lighter coloured and therefore brighter, helping visibility in both normal operating conditions and in emergencies.
- **Enhanced robustness** of the concrete pavement reduces tunnel closures and roadworks. Closures with diversions cause pollution and roadworks put site workers at risk.

In its extensive guidance on reducing risks in tunnels, international re-insurer, Munich Re (2003, p.20), states that a carriageway of non-combustible material (e.g. concrete instead of asphalt) must be considered in road tunnels. Some regulators have also acknowledged the fire safety role that concrete can play in tunnels. From 2001, a decree in Austria required that all new road tunnels longer than one kilometre in length used a concrete pavement. Slovakia also uses concrete pavements in all new tunnels and concrete is recommended for new tunnels in Spain (CEMBUREAU, 2004).

Kinkempois Tunnel (link E25-E40) in Liege, Belgium, using concrete pavement

Figure CS5.2:
Concrete road surfaces will stand up to the extreme temperatures encountered in tunnel fires.

It must be remembered that tunnel fires are likely to be some of the most extreme fires experienced. With these very high temperatures, some spalling from concrete surfaces is to be expected (see Section 2). Much research effort has gone into developing lining materials to minimise the effects of spalling from concrete surfaces when exposed to severe fires (e.g. Khoury, 2000). There is clear evidence that the addition of monofilament polypropylene fibres to the concrete mix is an effective solution and creates a concrete that can 'breathe' in a fire situation, making it less likely to spall.

Concrete prevents contamination of the environment

Concrete itself does not produce smoke or toxic gases in a fire and it can help to prevent the spread of environmentally harmful fires and their fumes. The use of concrete compartments and separating walls means that only a limited volume of goods can burn, which reduces the quantity of combustion products, such as smoke, fumes, toxic gases and harmful residues. In the event of a fire, concrete containers or bunds can also act as protective barriers against spills of environmentally harmful liquids or firefighting water that has become contaminated. During a fire, concrete will not deposit soot that is difficult and hazardous to clean up.

Fire safety in residential buildings

The European requirements on fire safety discussed in Section 1 cover life safety, mentioning residential building specifically because the risks are so significant – houses and apartment buildings may be densely populated, have high fire loads from furniture and fittings and we must not forget that sleeping people are at greater risk than when awake. All these factors mean that housing deserves particular consideration in fire safety design. It is not structural collapse following a fire that accounts for most residential fire deaths – it is inhalation of smoke or gases from burning materials and the resultant inability of occupants to escape (Neck, 2002).

In Europe there are two important reports have been produced that demonstrate improved fire safety with concrete construction.

1. A comparison of fire safety in timber and concrete residential buildings

In a comparison of fire safety in concrete and timber frame construction, Professor Ulrich Schneider of Vienna University of Technology identified that seven specific risks arise from the use of a combustible construction material (such as timber) within a building structure and envelope (Schneider and Oswald, 2005); these are listed in Panel 1

Panel 1: Risks of using combustible construction materials

1. An increase in fire load.
2. An increase in smoke and pyrolysis products.
3. Higher amounts of carbon monoxide.
4. Fire ignition of structural elements.
5. Fire ignition inside construction cavities.
6. Danger of smouldering combustion and imperceptible glowing (pockets of embers).
7. Increasing occurrence of flashovers.

Schneider went on to examine fire death statistics from various countries and established a clear link between the number of fire victims and construction materials used in buildings, as shown in Figure 4.1. His detailed study of typical timber construction details showed that failure in a fire could occur through ignition and collapse of structural or non-structural elements and via metallic connectors within the timber structure, which soften on exposure to fire and lose their loadbearing capacity. Schneider also found that fire spread between adjacent rooms and/or apartments was accelerated significantly in buildings where timber materials or cladding had been used as part of the external wall. In conclusion, Professor Schneider describes timber frame construction as having '*a multitude of weak points in terms of fire safety*' and recommends that: '*Timber frame structures can in principle only be made safe either by using automatic fire extinguisher systems or through the use of non-flammable building materials for fire proofing cladding of all flammable surfaces, as is provided for in new specimen guidelines for timber frame construction*' (Schneider and Oswald, 2005).

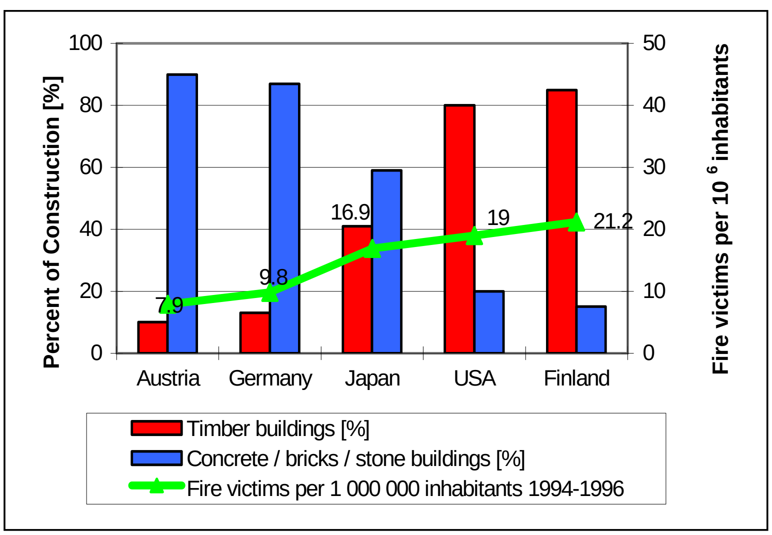


Figure 4.1: Fire deaths compared with construction type in five major countries (1994 – 1996). *(TUW, Vienna, Schneider and Oswald 2005)*

2. Independent fire damage assessment

In Sweden, Olle Lundberg undertook an independent investigation of the cost of fire damage in relation to the building material with which the houses are constructed, based on statistics from the insurance association in Sweden (*Forsakringsforbundet*). The study was limited to larger fires in multi-family buildings in which the value of the structure insured exceeded €150k; it covered 125 fires that occurred between 1995 and 2004. (These amounted to 10% of the fires in multi-family homes, but 56% of the major fires.) The results showed that:

- The average insurance payout per fire and per apartment in timber houses is around five times that of fires in concrete/masonry houses (approx €50,000 compared with €10,000)
- A major fire is more than 11 times more likely to develop in a timber house than in one built from concrete/masonry.
- Of the burned houses, 50% of the timber houses had to be demolished, compared with just 9% of the concrete ones.
- In only three of the 55 fires in concrete houses did the fire spread to neighbouring apartments.
- Of the 55 fires, 45 were in attics and roofing; typically the fire starts in the upper dwelling, it spreads to the attic and roofing (wood).

These research studies provide important evidence of the risks associated with timber frame construction and highlight the need to consider all the fire safety benefits of concrete and masonry construction. As discussed previously, the combination of concrete's non-combustibility and its highly effective fire shielding properties make it the best choice for safe residential buildings.

Case study 6

Timber construction site fire, Colindale, London (2006)

During the construction of a major new residential complex in North London, a fire broke out and ignited several six-storey timber frame blocks (see Figures CS6.1 to 3). The fire burned for five hours; it took 100 firefighters and 20 fire engines to bring it under control. Eyewitnesses reported that the blocks were destroyed within minutes. Shortly after the fire, an air quality monitoring station nearby recorded a significant rise in toxic PM10 particulates, which can have serious health implications for people with breathing difficulties. About 2,500 people were evacuated from the surrounding area, a major road was closed for two hours and a local college hall of residence was affected so badly that students could not return. Fortunately the housing development had not been occupied by new residents and the college was largely empty during the summer holidays. Nevertheless, the disruption was significant. Local building control officers expressed concern, noting that "*if you have concrete floor design and there's a fire, then it's going to compartmentalise. If you have timber, it's going to burn right through*" (*Building Design*, 21/07/06, p.1). At the time of writing, at least one block of the development was due to be rebuilt – this time using concrete.

Figure CS6.1
The fire at Colindale raged for five hours in the partially constructed timber frame residential blocks and took 100 firefighters with 20 fire engines to control it.
(Courtesy John-Macdonald-Fulton, UK)

Concrete prevents fire spread following earthquakes

The seismic design considerations that apply in some countries require designers to pay attention to the specific problem of fires following earthquakes. This has been given due consideration in countries such as New Zealand, where concrete structures have been identified as having a low level of vulnerability to the spread of fire following earthquakes (Wellington Lifelines Group, 2002).

Concrete protects possessions – fire protection with concrete means property safety and early return to business activities

5. PROTECTING PROPERTY AND COMMERCE

Concrete buildings and structures are capable of protecting both people and property against the hazards of fires, but understandably the safety of people often assumes the greater importance both as the design stage and in emergency situations. However fire safety for reasons of economic survival, environmental protection and upkeep of critical infrastructure is also of concern to private owners, insurance companies and national authorities. These factors are taken into account in European legislation on fire safety (see Section 1), with one of the three protective aims based specifically on protection of property, neighbouring properties and preservation of the building itself.

Concrete protects before and after the fire

The total monetary cost of fire damage has been estimated as typically 0.2 to 0.3% of gross national product (GNP) per annum (see Table 5.1). Clearly, for European countries this will run into many millions of euros but it does not give an adequate indication of the potential scale of the impact of a fire – Denoël/Febelcem (2006). In *Usine enterprise* (2004) it is stated that more than 50% of businesses go bankrupt after suffering a major fire. For commercial enterprises like warehouses, hotels, factories, office blocks and distribution centres, fires disrupt the function and productivity of businesses and interrupt service to the customer. This causes severe problems and may ultimately result in job losses or closure. However, the scale of impact on buildings with a critical infrastructure role could be even more far-reaching; such buildings include hospitals, railway stations, water and power stations, government buildings, data storage and telecommunications facilities. Disruption to these types of buildings is undesirable and potentially devastating.

Table 5.1: International statistical data on building fires 1994 – 1996 (Neck, 2002)

Country	Costs of direct and indirect fire damage (% GNP)	Deaths per 100,000 inhabitants per year	Costs of fire protection measures (% GNP)	Cost of damage and protective measures (% GNP)
Austria	0.20	0.79	NA	NA
Belgium	0.40 (1988–89)	1.32	NA	0.61
Denmark	0.26	1.82	NA	NA
Finland	0.16	2.12	NA	NA
France	0.25	1.16	2.5	0.40
Germany	0.20	0.98	NA	NA
Italy	0.29	0.86	4.0	0.63
Norway	0.24	1.45	3.5	0.66
Spain	0.12 (1984)	0.77	NA	NA
Sweden	0.24	1.32	2.5	0.35
Switzerland	0.33 (1989)	0.55	NA	0.62
The Netherlands	0.21	0.68	3.0	0.51
UK	0.16	1.31	2.2	0.32
USA	0.14	1.90	NA	0.48
Canada	0.22	1.42	3.9	0.50
Japan	0.12	1.69	2.5	0.34

With concrete, fire protection comes free of charge

This may come as a surprise because global data on the cost of fire protection indicates that around 2 to 4% of construction costs are typically spent on fire protection measures (see Table 5.1), but with concrete fire protection is an integral and therefore complimentary benefit. In fact, concrete has a reserve of fire security that stays effective even after change of use, or if the building is altered.

Concrete's fire safety properties do not change over time and remain consistent without incurring maintenance costs.

The inherent fire resistance properties of concrete elements enable them to fully satisfy fire protection requirements economically; they also make it somewhat future-proof to minor changes in fire safety legislation. However, if a fire does occur, investment in a concrete building will really make sense. Whether at home or at work, continuation of social and business activities is a priority and it is in this respect that concrete's performance in fire delivers immediate and significant economic benefits:

- The fire resistance properties of concrete mean that any fire should have been **limited to a small area,** room or compartment, minimising the scope and scale of repairs needed.
- **Repair work to concrete buildings affected by fire is usually minor,** straightforward and inexpensive because it is often only small areas of the concrete surface that will require repair – part or full demolition is unusual (see Section 2).
- **Concrete compartment walls and floors prevent fire spread,** so adjacent rooms in a factory, warehouse, office, or adjacent flats within an apartment building, should be able to continue functioning as normal once the emergency is over, no matter what the condition of the fire-affected area.
- In industrial and business premises, **concrete fire separation walls prevent loss of valuable possessions,** machinery, equipment or stock, thereby limiting the impact on the business and reducing the level of insurance claim to be made.
- Experience shows that in concrete buildings **water damage is negligible** after a fire.

Lower insurance premiums with concrete

Every fire causes an economic loss and in most cases it is insurers that have to pay for the damage caused by fires. For this reason, insurance companies maintain comprehensive and accurate databases on the performance of all construction materials in fire – they know that concrete offers excellent fire protection and this is reflected in reduced insurance premiums. Across Europe, insurance premiums for concrete buildings tend to be less than for buildings made from other materials (which are more often affected badly or even destroyed by fire). In most cases, concrete buildings are classified in the most favourable category for fire insurance due to their proven fire protection and resistance. Of course, every insurance company will have its own individual prescriptions and premium lists; these differ between countries, but because of concrete's good track record, most offer benefits to owners of concrete buildings. When calculating a policy premium, insurers will take the following factors into account:

- Material of construction
- Type of roof material
- Type of activity/building use
- Distance to neighbouring buildings
- Nature of construction elements
- Type of heating system
- Electric installation(s)
- Protection and anticipation (preparedness)

Case Study 7

Insurance premiums for warehouses in France

Unfortunately, very little data on insurance costs is made publicly available, but some comparative studies do exist. In France, CIMbéton (2006) published a summary and insurance cost model based on insurers' views of single-storey warehousing/industrial buildings. The study explains that insurance premiums are based on a number of factors, including the activity within the building and construction material. The building material is certainly important – the structure, exterior walls, number of floors, roof covering and furnishings are all taken into account in the calculations. The results show clearly the extent to which concrete is preferable to other materials, such as steel and timber, for all parts of the building. For example, by selecting a concrete frame and walls for a single storey warehouse means a possible 20% reduction on the 'standard'/average premium paid. Changing this for a steel frame and cladding option would add 10 to 12% to the 'standard' premium, therefore making at least a 30%

difference in total. In deciding the final premium, the insurers also take into account security equipment, fire prevention and suppression measures, which includes compartmentation – a fire prevention option in which concrete excels.

Table 5.2: Insurance premiums for a 10,000 m^2 warehouse (single storey, no furnishings); total insured = EUR 25 million (CIMbéton, 2006).

Construction	Annual premium (excluding tax) Average annual rate = EUR 50 000
Concrete	EUR 40 000 (20% less than average rate)
Steel	EUR 56 000 (12% more than average rate

CASE STUDY 8

Destruction of abattoir, Bordeaux (1997)

Caused by a short circuit in the ceiling, this spectacular fire spread very quickly, engulfing 2000 m^2 in 10 minutes. It took three hours for firefighters to bring it under control, and by this time half of the 9000 m^2 building was burnt out. This extremely fast spread was caused by the ignition of the combustible insulation material contained in the sandwich panels used for the building's façade – the firefighters could not stop it spreading along the 130 m façade (as show in Figure CS8.1). It is clear that the division of the building into compartments with concrete walls, and the use of concrete façade panels would have restricted the spread of this fire.

Figure CS8.1:
The light-weight sandwich metal panels failed in this abattoir fire in Bordeaux (France) in January 1997. The fire spread throughout the building and to adjacent buildings. (*Courtesy SDIS 33, Fire and Rescue Service, Gironde, France)*

CASE STUDY 9

Fire in clothing warehouse, Marseille (1996)

The fire spread very quickly in this clothing and sports equipment warehouse where 40 staff were working at the time; in five minutes the whole building was on fire, the burning goods generating a quantity of smoke and heat. There were no sprinklers and no compartment walls, and the building structure was unstable in the fire, resulting in complete destruction as shown in Figure CS9.1. The wind helped spread the fire, which threatened nearby warehouses, 10 m away, from which the staff had to be evacuated. These other buildings were only saved by the firefighters providing a curtain wall of water.

Figure CS9.1
Aerial view of the burnt out warehouse north of Rognac, near Marseille, showing how the fire spread throughout the building which had no concrete separating walls.
(*Courtesy SDIS 13 Fire and Rescue Service, Bouches du Rhone, France)*

Concrete helps firefighters save property

Despite the European legislation demanding protection for people, property and the environment, in most cases the fire brigade's obvious and practical priority is the protection of human life and so protocols concerning their entry to a burning building tend to be based on placing the rescue of occupants first, with the protection of property and the environment coming second. For example, firefighters may be extremely reluctant to enter a building if all the occupants have evacuated. But they will always try to approach the building as closely as possible in order to fight the fire effectively. Concrete façades provide protection to permit such an approach. Once they are satisfied that all the occupants are safe, firefighters may be more concerned with preventing fire spread to adjacent properties and assessing any risks to the environment caused by combustion products. This understandable approach reinforces the need for people to be able to escape safely from a building at least within the regulatory period of fire resistance.

Research in France shows that, of the 13,000 fires per annum, 5% occur in industrial buildings and a large fire can result in €2 million of operating losses (CIMbéton, 2006). In these buildings, the stock may be highly combustible and present in very large quantities, which presents a very significant risk of collapse in fire, unless compartments are used effectively to divide up the stock and consequently the fire load. Consider then, the example of a warehouse owner who is keen to minimise stock damage in the event of a fire, but knows that the fire brigade may insist on fighting the fire at a safe distance, from outside the building. In this case, concrete can provide some distinct advantages:

1. Depending on the type of stock and size of compartment, the fire load in these buildings can be very high. Regularly spaced, internal concrete compartment walls will **reduce the risk of fire spreading** from one room to another, thereby minimising the level of damage incurred.
2. With single-storey, long-span, single compartment buildings there is a particularly high risk of early, sudden collapse of the roof. **Concrete walls will retain their stability** and even if a roof truss collapses, the walls should not buckle and collapse, putting any adjacent areas at risk.
3. Fire-resistant façades in concrete (classified as REI 120) prevent fire spread and protect firefighters (see Figure 1.2). **Concrete façades enable firefighters to approach about 50% closer to a fire** because they act as a heat shield.
4. **Concrete external walls are so effective in preventing fire spread** between properties that the regulations in some countries (e.g. France) allow the distances between adjacent buildings to be reduced from that required for other walling materials.
5. **A concrete roof will be incombustible**, i.e. class A-1 flame proof and will not drip molten particles.

Case study 10

International flower market, Rungis, Paris (2003)

This 7200 m² concrete flower warehouse and packing facility largely survived a damaging fire in June 2003. The walls and ceiling stood up well to the fire, which generated a lot of heat and fumes when the materials used for bunching and packing caught alight, aided by the aromatic oils in the plant material. The whole of the southern part of Paris was affected by smoke as an area of 1600 m² of goods and equipment were destroyed. Although 100 m² of the building collapsed, the fire was contained in the area where it started and six months later, despite lengthy insurance evaluations, the building was repaired and operations resumed.

Figure CS10.1:
Exterior view of the flower warehouse in Rungis, which was back in business six months after the fire. (*Courtesy CIMbéton, France)*

Figure CS10.2:
The damaged interior of the warehouse, which was quickly repaired. *(Courtesy CIMbéton, France)*

Concrete offers built-in fire resistance, so building owners do not have to rely on active systems to protect life and property

6. CONCRETE AND FIRE SAFETY ENGINEERING

How fire safety engineering works

Fire safety engineering (FSE) is a relatively new way in which fire protection measures can be calculated, based on performance-based methods rather than prescriptive data tables. It has been used mainly for large, complex structures (such as airports, shopping malls, exhibition halls and hospitals) to minimise requirements for fire protection measures. There is no single definition for FSE, but ISO defines it as the "Application of engineering methods based on scientific principles to the development or assessment of designs in the built environment through the analysis of specific fire scenarios or through the quantification of fire risk for a group of fire scenarios" (ISO/CD).

The design procedure used in fire safety engineering takes into account the following factors to calculate the design value of the fire load, from which individual structural members can be assessed and the overall probability of a fire causing structural damage can be established:

- The characteristic fire load density per unit of floor area (values for these are given in EC1, Part 1–2).
- The expected fire load caused by combustion of the contents (combustion factor).
- Fire risk due to the size of the compartment (large compartments are given a higher risk factor).
- The likelihood of a fire starting, based on occupants and type of use (use factor).
- Ventilation conditions and heat release.

The calculation method then takes advantage of all active firefighting measures within the building, which are aggregated, to give the fifth and final factor in the fire load calculation, which includes:

- Automatic fire detection (e.g. heat alarms, smoke alarms, automated transmission of alarm to fire brigade station)
- Automatic fire suppression (e.g. sprinklers/water extinguishing systems, availability of independent water supply)
- Manual fire suppression (e.g. on-site fire brigade, early intervention of off-site/local fire brigade).

Fire safety engineering in practice

Common rules for fire safety engineering methods do not exist, user-friendly software is still under development and there are significant variations in approach, experience and levels of acceptance by authorities. FSE has to be used with care through appropriate experts and proper evaluation of its assumptions. Serious concerns have been raised about the validity and accuracy of the probability-based calculations, with critics noting that a faulty FSE calculation could lead to a catastrophe. Others have voiced fears that inexperienced, inexpert attempts to use FSE could lead to misunderstandings in calculations and the wrong results. Large variability of parameters within the assumptions underpinning the calculations could include, but are not limited to, the following aspects:

- **Fire brigade success rates**: again, average values are provided, but are clearly not applicable to all buildings; there will be significant variation in performance.
- **Human behaviour**: assumptions are made on how people will behave in an emergency, but there is a very high degree of variability here related to crowd behaviour and means of escape.
- **Reliability of sprinkler systems**: average values are given, but there are many types of systems to suit all types of buildings.
- **Arson or deliberate fires** (i.e. caused by criminal intent) – these are not really covered sufficiently. Some building types and locations will naturally be more vulnerable to crime.

Some statistics on the observed performance of sprinkler systems indicate poor levels of reliability. Febelcem (2006 and PCI (2005) reports findings from the USA, in which the National Fire Protection Association noted that sprinklers had failed in 20% of hospital/office fires, 17% of hotel fires, 13% of apartment fires and 26% of public building fires, leading to a national average failure rate of 16% (2001 figures). Figures from Europe cited in the same publication paint a slightly better picture.
Sprinkler success rate analysed by risk class showed the following:
Offices (light risk) 97.4% success
Business (medium risk) 97.2% success
Timber industry (high risk) 90.8% success.

Other sources claim that many such failures are due to human interference with sprinkler heads (e.g. covering with paint, hanging items etc). Nevertheless, the efficiency of sprinkler systems can be affected by an inherent problem caused by interaction between smoke (venting) systems and sprinkler systems. A number of studies have found that sprinkler water cools the smoke plume, destroying its upward buoyancy; the smoke therefore does not rise, causing a loss in visibility during evacuation (Heselden, 1984; Hinkley and Illingworth, 1990; Hinkley et al, 1992). Furthermore, the upward movement of the smoke plume being drawn out by automated, mechanical smoke venting prevents water droplets from the sprinklers from descending efficiently and quenching the fire.

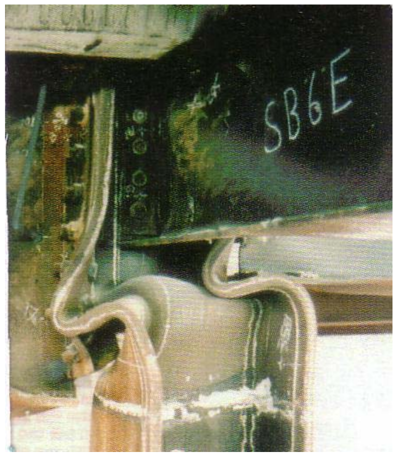


Figure 6.1
Severely deformed steel column head following a fire.
(Courtesy Building Research Establishment, UK)

The design procedures used in FSE are based on the premise that the inclusion of the various active firefighting measures reduces the likelihood that a fire will cause structural damage; a combination of these measures has a multiplying effect, reducing further the assumed fire load density in the building. This calculation method therefore reduces the fire protection apparently needed in a building. The result is that some construction materials, that are in fact weak in fire and totally dependent on active firefighting measures, may appear to be viable structural options.

In FSE, the fire resisting capacity of a structure is obtained by considering the fire extinguishing system and applied protection to the structure. But FSE may fail to protect a building, its occupants and its contents. The reason is shown in Panel 2.

Panel 2: Why FSE strategies may not work
The fire extinguishing system may not be effective because:
- It fails or
- It is not adequate for the fire

The fire protection may not work because:
- It fails
- It has aged
- It has deteriorated or
- Is not adequate for the fire

At this stage the fire resisting capacity of the structure will revert to the inherent fire resistance of the materials that form the structure, whether this is concrete, timber, brick or steel.In this case the FSE strategy can fail instantaneously because unprotected steel and timber members will not maintain their loadbearing capacity without fully functioning active fire protection systems.

In normal cases concrete is the **only** material that can provide robust fire resistance unaided by active measures; it is a passive firefighting measure that will act reliably when active measures fail. Fire safety engineering can undervalue proven and maintenance-free passive measures like concrete construction and could lead to an unfortunate over-reliance on unreliable active systems, potentially jeopardising lives and property.

With concrete, the fire safety measures will still apply even when there has been a change in use, because concrete is inherently fire resistant. Where protection is provided by FSE this will only apply to situations where the use does not change. This is because FSE measures are determined by taking the use of the building into account. If anything changes, for example the fire load, then the protection provided by sprinklers or fire coating may no longer be sufficient.

Concrete provides even more than comprehensive fire protection

7. THE ADDED-VALUE BENEFITS OF CONCRETE

Concrete's excellent and proven fire resistance properties deliver protection of life, possessions and environment in the case of fire. It responds effectively to all of the protective aims set out in European legislation, benefiting everyone from building users, owners, business people and residents to insurers, regulators and firefighters. Whether it is used for residential buildings, industrial warehouses or tunnels, concrete can be designed and specified to remain robust in even the most extreme fire situations.

Not only does concrete have superior fire resistance properties, but it also provides thermal mass and acoustic insulation

The combination of these three performance attributes enable the designer to maximise the possible benefits. For example, installing a concrete separation wall between adjacent fire compartments provides the necessary fire protection, adds thermal mass to help maintain temperatures and gives acoustic separation between the spaces. All of this is possible with just one material, without having to rely on active measures, the addition of further insulation or intumescent materials, carrying out frequent maintenance or refurbishment. Clearly, concrete has a major long-term economic advantage in this respect, but more importantly it has a long-term fire safety advantage.

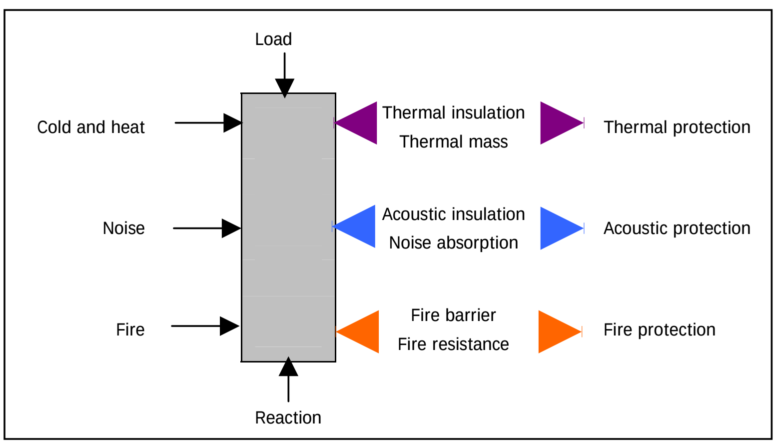


Figure 7.1
The added-value benefits of concrete.
(*Courtesy Neck, 1999*)

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