ICE Publishing

Hertz, KD
ISBN 978-0-7277-6444-7
https://doi.org/10.1680/dofrcs.64447

Chapter 2
Fire exposure

2.1. Fire

2.1.1 Standard fires

Originally, structural fire research involved wood cribs or coal fires like that shown in Figure 2.1. However, these have the obvious disadvantage that the fire impact on the structure varies literally as the wind blows. You can hardly relate such test results to the outcome of real fires or to the results of other tests.

Figure 2.2 shows an illustration of a fire test conducted in New York in 1902 in a wood-fired oven. Shortly after, city gas was introduced to New York and Professor Ira Woolson soon applied it for column tests at Columbia University. In doing so, he could not only ensure a smooth heating curve and better means for adjusting the temperature at all levels of heating, but he could also compare results from one test with another because of the well-defined fire impact. Fire test ovens have come a long way since then (Figure 2.3).

Woolson's temperature–time curve became the 'standard fire' curve defined in the ASTM C19 standard (later ASTM E119) (ASTM, 1918). The international standard for fire testing ISO 834 was published later (ISO, 1975), with different countries applying slightly different fire curves in order to prevent competition in their home markets.

Figure 2.1 Johann Baushinger's column fire test, Munich 1884 (drawing by KD Hertz)

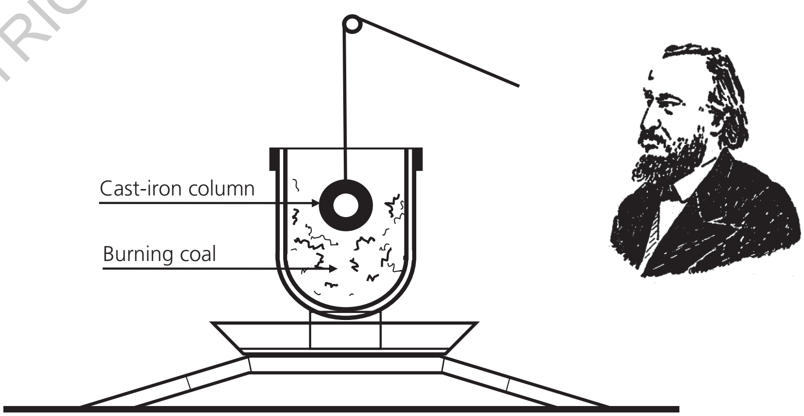
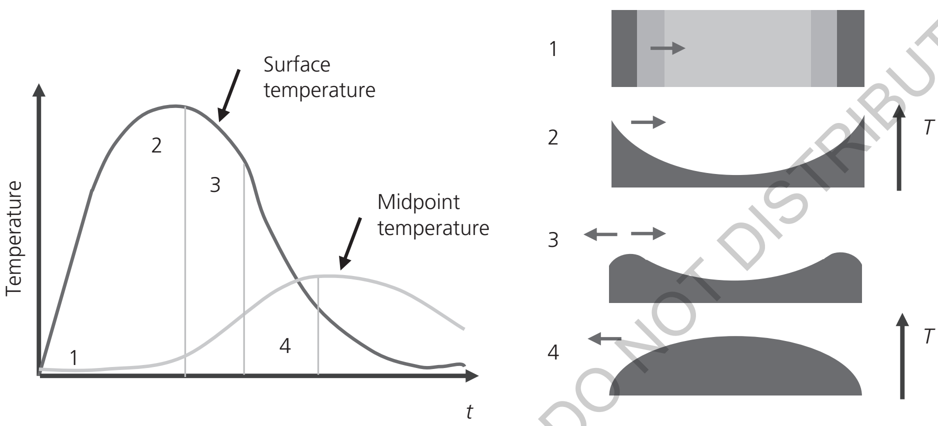


Figure 3.2 Temperature distribution during heating and cooling



At the beginning of the cooling period (3) some of the heat in the outermost layers will move out of the cross-section, but some of it will move into the core. This means that the outermost levels are cooling down while the core is heating up. Here you have to assign the HOT values for the concrete strength according to the actual temperatures in the core. However, in the surface layers, you have to apply the HOT values of the concrete strength for the maximum temperature that has been reached at each depth.

Later in the cooling period (4), you have to apply the maximum temperatures that have been reached at all depths. This represents the minimum concrete strength. To ensure that you calculate the absolute minimum, for each depth you should apply the minimum compressive strength of the concrete, which is the COLD value for the maximum temperature that has been reached at that depth.

If you are calculating for a plain concrete structure without reinforcement, the strength of the structure will be the smallest after the cooling period 4. We call this the 'COLD condition'. If you design your plain concrete structure for a certain time of a standard fire without cooling, you should apply the strength reduction profile at time 2, the HOT condition. However, the standard fire standard also defines a cooling period and, if that is applied, you may consider a COLD condition for that.

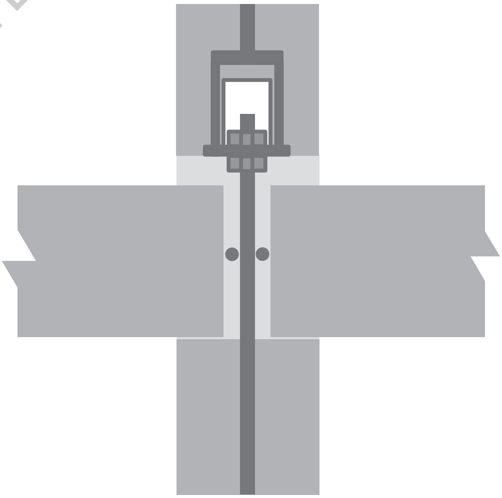
However, engineers almost never do this.

Figure 4.41 Fire-damaged pretensioned beams in a factory (photo T Jakobsen)

The central connection detail in most prefabricated concrete building systems is a floor–wall connection. Figure 4.42 shows an example.

In May 1968, a corner of a 22-storey tower collapsed at Ronan Point in West Ham, London, due to a gas explosion on the 18th floor. Following this collapse, designers started to apply stirrup connections to establish continuous tensile stringers in the shear walls and authorities

Figure 4.42 Floor–wall connection with stirrup



Since about 1990, drilled tunnels have been constructed with a curved lining of high-strength concrete of approximately 100 MPa. In this way, a circular shell of high-strength and water-tightness is obtained in a simple manner using only one material for the elements. However, in real fires, such tunnels experience explosive spalling.

During construction of the Great Belt tunnel (Figure 4.56) in Denmark, in June 1994, a drilling machine caught fire. Up to two-thirds of the 40 cm thick tunnel element spalled away.

External pressure on a circular cross-section produces compressive stresses in the elements forming the tube. When a fire occurs inside, the temperature of the innermost layers increases. However, because of symmetry, the tubular cross-section is unable to stretch out and large additional compressive stresses develop along the inner surface, increasing the risk of explosive spalling (Figure 4.57).

After this incident, the author tested a spare element for Danish television in order to demonstrate the effect of explosive spalling. This element had spalled even though it was not part of the full circle and, as such, was only subjected to minor compressive stresses from hindered thermal expansion along the inner surface (Figure 4.57).

Figure 4.56 Cross-section of drilled tunnel under Great Belt

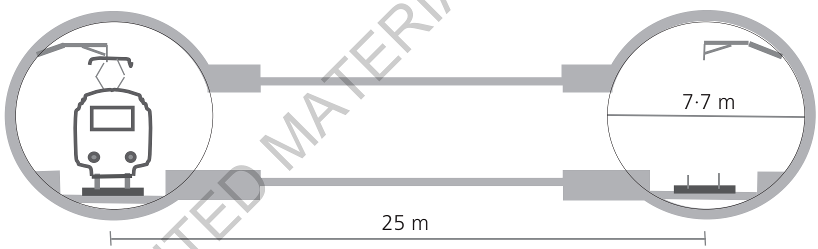
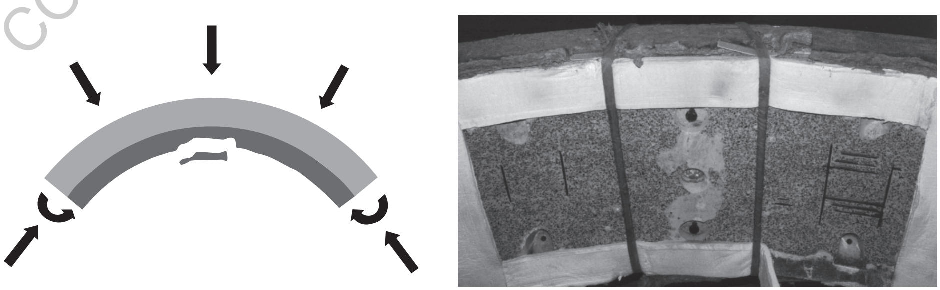


Figure 4.57 Principle of explosive spalling of a curved tunnel element and spalled inner surface of a tunnel element tested by the author



The contractor placed a 1 m thick wall in the tube, behind which a crew of workers repaired the concrete elements in compressed air. Since then, more fires have occurred in trains passing through the tunnel. However, all have been able to drive out, with the fire extinguished at a nearby station.

In another incident, a train carrying trucks caught fire in the Channel Tunnel at the border between France and England in November 1996. The fire lasted a couple of hours more than necessary from a technical point of view. The reason for this was that the authorities had to obtain paperwork to allow the Kent fire brigade to cross the border into France to extinguish the fire in the rest of the train. In this fire, most of the cross-section thickness spalled away, leaving only 25 mm of concrete where the tunnel was damaged the most.

Fortunately, the accident happened at a place where limestone rock surrounds the tunnel so the tunnel lining did not collapse.

In March 1999 a lorry caught fire in the Mont Blanc tunnel and several vehicles were burned out. The tunnel suffered from such severe explosive spalling that naked rock was visible through large holes in the ceiling.

These examples confirm the theory that circular tunnels with walls made of high-strength concrete are susceptible to explosive spalling in the event of fire.

4.7.2 Immersed tunnels

Rectangular cross-sections are often used for immersed tunnels. An example is the Fehmarn Belt connection, shown in Figure 4.58.

In principle, this structure is a frame and may therefore be designed for fire according to the principles referred to in Section 4.5.2.

Immersed elements need to be heavy in order to counteract buoyancy. The thickness of the outer concrete structure is therefore often 1 m or more and, at the middle of a span, the compression stresses on the inner side are smaller. The risk of collapse due to explosive spalling is therefore often smaller than for the drilled tunnels with circular cross-sections and relatively thin shells.

Figure 4.58 Immersed tunnel cross-section of the Fehmarn Belt tunnel