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New Year revolutions

WHAT WILL be the themes of 1997? Here at *New Civil Engineer*, preparations are well in hand for our Silver Jubilee celebrations, including our 25th anniversary issue on 8 May. We hope that *NCE* turning 25 does not make too many of you feel too old, though it has that effect on certain colleagues here who remember the early days.

The other big event of the year is the inevitable general election. The pollsters got it spectacularly wrong in 1992 and John Major scraped back in. It is hard, however, to envisage him repeating the trick and a change of government after 18 years appears likely, though not quite as certain as the opinion polls have thus far suggested.

A third theme, God willing, is recovery. After three, four or even six dire years for civil engineering – depending on your sector – the signs are growing clearer that 1997 may indeed be the turning point that the forecasters have predicted. The traditional collapse of political decision-making in the run up to and in the wake of a general election normally takes its toll on the construction industry. But today with so many clients now in the private sector, the effects are mitigated.

One of the stronger indicators of recovery is that the recruitment industry has got its tail up. Civil engineers are harder to find, or at least the ones of the right calibre and age. This may be bad news for employers and industry clients, but for the basic self-interest of you the reader, your salary is likely to rise as a result. May you get what you wish for. Happy New Year!

Millington

"For this bright, enthusiastic, 28 year old civil engineer, with site and design experience – do I hear £30K?"

Fire factors

A new fire safety strategy needs to be developed for the Channel Tunnel, argues Dr Gordon Cooke, international fire safety consultant and visiting professor in the department of civil engineering at City University.

The contract is about to be let by Eurotunnel for repair of the Channel Tunnel lining structure which was severely damaged by fire in a heavy goods vehicle shuttle train on 18 November 1996. Damage to a 280m length was rated as serious and to a 40m length, now supported by colliery arches, very serious. Cost of reinstating the structure and services is put at £50M. Other costs in loss of revenue are far larger and more difficult to quantify.

Full operation of the tunnel may not be re-established until six months after the fire, so it is clearly important to understand what the present construction is, why the damage was so severe, and to ensure that such damage cannot occur again.

The running tunnel is lined with precast high strength concrete segments 1.6m wide and approximately 400mm thick. Each segment is reinforced with a cage of high performance reinforcing steel using 8mm and 12mm diameter high tensile steel bar and 8mm diameter cold-rolled wire. Several segments make up a ring and their geometry is complicated by the need for each ring to have a tapered end so that when placed end-to-end the tunnel lining can "bend" to follow the bored hole.

Each segment has a groove around and near the outer face to accommodate a watertight neoprene seal gasket and the annular space between the lining and the chalk wall is grouted with a mix of sand-based mortar and high alumina cement. The composite construction so formed is designed to be watertight and capable of withstanding a hydrostatic pressure of $100t/m^2$ for a minimum life of 120 years.

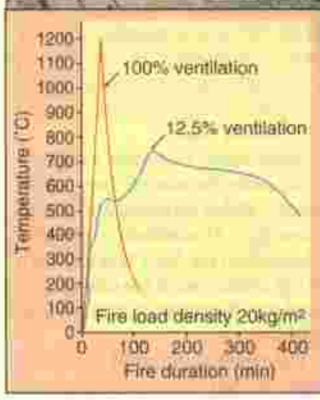
Two factors account for why so much damage was sustained during the fire: the tendency of the concrete to spall; and the severity of the fire.

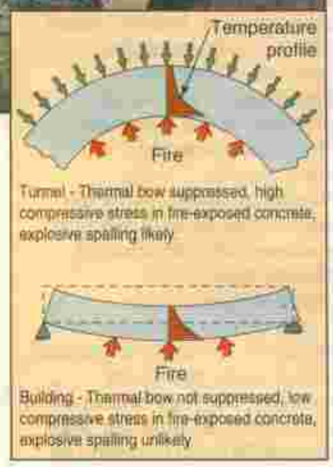
In the tunnel fire, explosive spalling caused the detachment of large amounts of concrete near the seat of the flames, while sloughing, which features the removal of thin layers (each typically 10mm thick), occurred further away where the heat was less intense. There are several unfortunate features which make the tunnel lining especially susceptible to explosive spalling:

- The circular form of the tunnel, the hydrostatic pressure acting on the outside of the lining via the grout (parts of the tunnel are 40m below the seabed) and, in the fire condition, the high level of hoop stress imposed by the outermost reinforcing steel/concrete of the lining. This means the high compressive stress generated in the concrete near the fire-exposed surface cannot be relieved, as it can in a building, by thermal bowing (figure 1).
- The low water/cement ratio and high level of compaction needed to achieve high strength when the concrete was made. This leads to a concrete with minimum porosity making it difficult for fire-generated moisture to escape without producing explosive pressures.
- The likely high moisture content of the lining due to the contact with the damp ground.

It is recognised in the literature that these factors have a significant effect on spalling. But how important is the thermal bowing effect? In tests in the standard fire resistance floor furnace made by myself on 4.5m long by 150mm thick simply supported reinforced concrete slabs, the specimens of normal weight concrete were exposed to the standard "cellulosic" (ISO 834) and the "hydrocarbon" (NPD) combustion gas temperature-time conditions. Mid-span deflections were measured with no imposed load.

The tests showed that thermal bowing deflections were larger than expected, and were especially large early on in the hydrocarbon fire exposure, but no spalling occurred. The suppression of thermal bowing, which occures in the tunnel ring configuration, can only lead to a greater tendency for explosive spalling.





The tunnel ring configuration is also the key to explaining why the fire was so severe, the second factor accounting for the large amount of damage sustained. Compared to a fire in a spacious room in a building, a fire in the Channel Tunnel (assuming the same fire load density) will be more severe because:

- the ceiling is low so that the thermal plume has less height through which it can beneficially entrain cooler air, hence the temperatures of the flames and ceiling jet will be high.
- again because of the low ceiling, the feedback radiation from flames and the hot gas layer travelling under the ceiling causes rapid fire spread to fuel packages nearby leading to an earlier occurrence of flashover.
- the absence of windows means that the fire effluent cannot beneficially escape to the outside air and the trapped heat causes more damage.
- radiation from the flame front is not beneficially "lost" to the outside as in radiation through a window opening in a building – radiation loss can account for a third of the heat generated in a fire in a building.

It is imperative that a fire occurring in open rolling stock in the tunnel must be suppressed at the earliest stage in its development to avoid major damage to the structure of the tunnel and M&E services, quite apart from life safety considerations.

In a fire in a conventional building the maximum combustion gas temperature that can be reached is around 1,200°C but the fire duration is short. Figure 2 shows ceiling temperatures achieved in tests I arranged in 1993 in a compartment nominally 23m long by 6m wide by 3m high with two extreme amounts of ventilation in one of the 6m wide walls. Reducing the ventilation area from 100% to 12.5% reduced the temperature (measured at a point 6m from the ventilation opening) from 1,200°C to 700°C but, more importantly, markedly extended the fire duration, by a factor of six using 500°C as a common cut off.

A stationary train in the Channel Tunnel would correspond to a low ventilation condition and, even assuming a very low fire load density of $20kg/m^2$, would lead to a long duration fire which would have a very punishing effect on the tunnel lining.

So it is imperative that a fire occurring in open rolling stock in the tunnel must be suppressed at the earliest stage in its development to avoid major damage to the structure of the tunnel and M&E services, quite apart from life safety considerations. Many strategies are possible:

- Construct all rolling stock as totally enclosed fire-resisting compartments so that fire could never spread from one wagon to another or into the tunnel. In the event of fire the train would be driven at high speed to the open air terminal where evacuation and fire fighting could take place safely and more effectively. Compartmentation can be achieved for the shuttle wagons. It is for the car shuttle but the HGV wagons are open-sided because there was a weight problem. This compartmentation strategy could not be adopted for through trains carrying goods and passengers.
- Construct all rolling stock with open tops, except for passenger wagons, and protect the entire tunnel length with a fire-intelligent fire suppression system. In the event of a fire, the train would be stopped and the suppression system, eg sprinkler or high expansion foam, would be operated to control or extinguish the fire. High expansion foam would have the additional benefit of plugging the gap between the rolling stock and the tunnel lining to prevent the flow of effluent. The suppression system would need to be fire-intelligent to avoid exhaustion of the suppression agent before the train came to a stop.
- Assuming that all the rolling stock is not constructed as fire resisting compartments, drive the train at a high speed through the tunnel on the assumption that the fire effluent will be diluted to such an extent that thermal damage to the tunnel will be minimal. This may be acceptable for a fire, but what about an explosion leading to a fire – malice cannot be ruled out.
- Stop the train in the tunnel, abandon the rolling stock on fire for fire fighters to deal with, and take the non-fire affected rolling stock out of the tunnel in both directions. This may not be easy if following trains cannot swiftly reverse out of the tunnel. This option appears impractical, as the fire on 18 November proved.

There are, of course, many possible fire protection, fire containment or fire suppression systems that could be exploited once the various accidental and malicious fire hazards and fire scenarios have been identified and their risks and cost implications quanitified. Bearing in mind the objectives of life safety, property protection, public confidence and financial viability, let us hope sufficient effort and lateral thinking has gone into present fire safety strategies and precautions.