INNOVATIVE. FIRE. SYSTEMS.
PASSIVE FIRE PROTECTION

IMMERSED TUNNEL
BJORVIKA - OSLO

HOW TO PROVIDE THE MOST DEMANDING FIRE PROTECTION IN THE WORLD

How to provide maximum fire protection:

Methodology used to calculate thermal aspects of the structures

When designing tunnel linings, building design rules are often used, such as Eurocodes. Generally the temperature within the concrete is calculated, which in turn gives the load-bearing capacity. These calculations work well for many applications, but they have their limits. In standard EN 19992-1-2, covering the Eurocodes for concrete structures, the material models are only valid for heating rates between 2 and 50°C/minute, because creep effects are not explicitly considered. The Norwegian Authorities feel that this gives erroneous results. They preferred to model their linings for this tunnel with faster heating rates, using the Dutch RWS time-temperature curves, which have maximum heating rates of 200 – 240°C/minute.

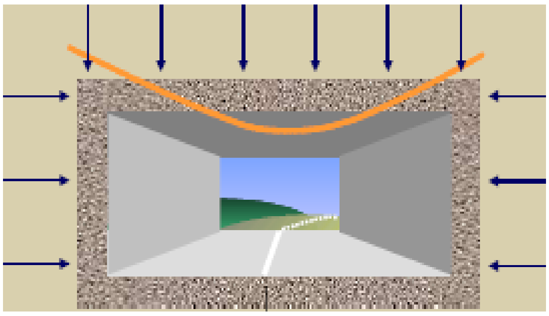
Forces induced by thermal dilatation in hyper-static structures

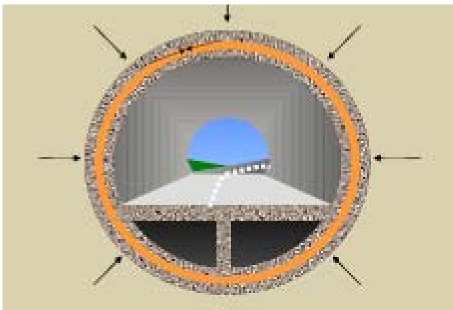
To determine the most appropriate fire protection lining, Swedish and Norwegian authorities ran a series of fire tests on loaded concrete in 2006, with three different products, and reached the following conclusions. Fire-resistance, in terms of temperature response and spalling, was determined experimentally for several different qualities of concrete. Concrete reinforced with polypropylene fibers gave very good results. However, there are still questions concerning the long-term durability of these fibers, particularly in terms of frost resistance and chloride ion penetration.

The most restrictive fire test in the world for tunnels

Tests performed on concrete with certain types of protection were not satisfactory because, even though the products used displayed previously documented results, they were found to be incapable of responding to the extreme stresses of this series of tests. In the present study, three different systems were tested under loaded slabs with a concrete compression force of 5.5 Mpa, and all failed. Consequently, in June 2007, the Norwegian public road directorate published a report (TR-2494) describing the method used for testing fire protection systems in tunnels.

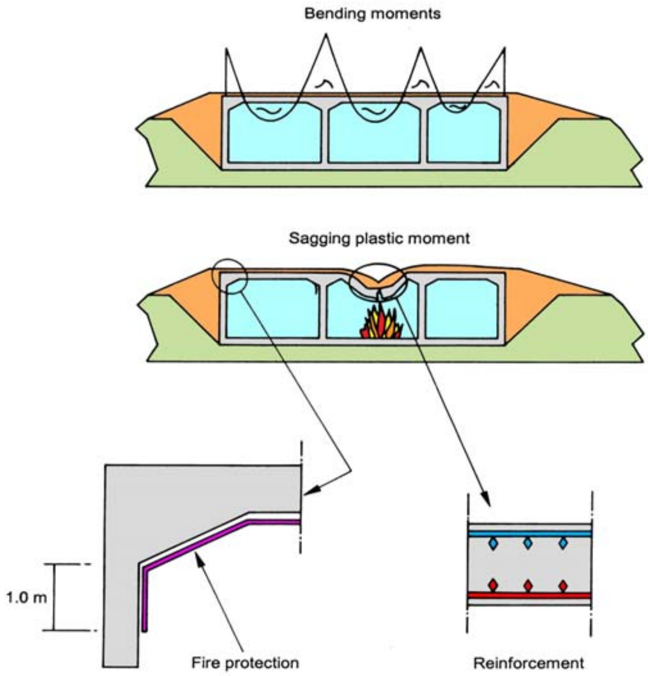
This shall be performed in accordance with the RWS fire curve, while duplicating as far as possible the bending moment of their hyperstatic structure, thus simulating the plastic moment created by the permanent load under rising temperature.





Immersed tunnel or Covered trench -- *Drilled tunnel*

The roads directorate did not want to duplicate the Dutch fire test methodology for drilled tunnels, which does not use any of the stresses which apply to hyperstatic structures.



Fire tests must therefore be performed on large concrete components post stress with a range of 3.6 meters, in a horizontal oven; a load of 4633 kN will be applied to the slab, to apply a theoretical compression strength of 12.9 MPa to the exposed surface.

On the other hand, the Norwegian authorities used the same philosophy as that of French circular 2000-63 recommendations of March 2005 (appendix F3.1) to perform tests on large loaded slabs (4m x 3m) and with a load applied (appendix F3.3).

Through these cumulative requirements for wide, loaded spans, with a 300 MW fire, we can say that Fire Barrier 13 successfully passed the most demanding fire test in the world for immersed tunnels and/or hyper-static structures.

Fire tests must be performed in an ISO 9001 or ISO/EIC 17025 certified laboratory. A frost resistance test shall also be required in accordance with EN 1387-1 (40 cycles from -20°C to 10°C), fatigue testing over 50 million cycles, high pressure cleaning resistance testing at 150 bar, alkali resistance and carbonation testing.

Fire Barrier 135 sprayed mortar performance:

INNOVATIVE FIRE SYSTEMS, the exclusive global distributor of FIRE BARRIER 135 since May 2003, has already signed more than 35 contracts for tunnels in France, Spain, Monaco, Italy and Egypt. For this project, Thermal Ceramics was the only supplier to take the risk of performing this series of tests, involving an investment of more than 150 000 EUR. The suppliers of inserted boards and vermiculite-based sprayed mortar (both members of the same group) did not attempt any further tests on their products following their initial failure with series of test Malmö, Sweden in 2006.

With 15 previous fire tests on FIRE BARRIER 135, performed in five different laboratories (TNO, CSI, CSTB, SINTEF, SP) respecting three different fire curves (RWS, HCinc, ISO) with several types of concrete (compression strength 35 to 76 Mpa), INNOVATIVE FIRE SYSTEMS and THERMAL CERAMICS decided to meet the Norwegian road directorate's requirements. With our FIRE BARRIER 135 system, we spent a year on intensive tests.

Several fire resistance, physical characterization and longevity tests were performed at the Swedish national test and research centre at Borås. The combustible load was dimensioned for a 300 MW fire lasting at least two hours, as per the RWS curve. The surfaces were protected with a 36 mm thick coating of FIRE BARRIER 135 reinforced with 1.9 mm diameter stainless steel wire mesh in panels of 50 mm x 50 mm, bound to the concrete with spacers and anchors places every 40 cm x 40 cm. After two hours, the average temperature at the interface was less than 265°C.

The alkali resistance test was performed according to Norwegian specifications. Fire protection must be hardened/conditioned for at least six (6) weeks at 23±2°C / 50±5 % RH before starting the test. A set of test samples (at least 5 samples) was immersed for two (2) days in 1N NaOH (1mole/litre of Sodium hydroxide) at 23±2°C, flushed with distilled water and conditioned at 23±2°C / 50±5 % RH for at least four (4) weeks. At the same time, another set of test samples (at least 5 samples) was conditioned at 23±2°C / 50±5 % RH for at least four (4) weeks without first undergoing the alkali attack.

An adhesion test was then performed on both series in accordance with EN 1542:1999. The adhesion of the fire protection to the reference concrete was not reduced by more than 20% by the effect of the alkali and the coating did not show signs of deterioration as a result of the alkali attack.

The carbonization resistance test was performed in accordance with standard EN 13295:2004, Resistance to carbonizing as a result of reaction to CO_2 produced by the traffic zone.

The following pressure/suction dynamic forces were applied for 15 million cycles: tear strength 1.97 kPa, compression 1.56 kPa.

The frost resistance test was performed in accordance with standard EN 13687-1:2002. The test ended after 50 cycles, each lasting 4 hours. It involved 2 hours immersion in a tank containing a saturated sodium chloride solution at a temperature of -15±2°C, followed by 2 hours storage in a water tank at a temperature of 21±2°C.

The fatigue test was performed according to Norwegian specifications: the fire protection, including mechanical anchoring, fulfilled the requirements of the relevant traffic loads in the tunnel. The volume of traffic measured was 100 000 vehicles per day.

The high pressure cleaning test was also performed in accordance with Norwegian specifications. The fire protection and its surfaces must tolerate normal periodic tunnel washing: 120 cleaning operations were performed from 50 to 150 bar for one minute over one m² with a water flow rate varying from 10 to 25 litres/minute/nozzle, with 500 mm between nozzles and fire protection, to simulate total life expectancy.

Fire Barrier 135 sprayed mortar installation operations:

INNOVATIVE FIRE SYSTEMS has extensive experience in the application of fire barrier 135 application on worksites where time is a premium. In the Bjorvika tunnel, I.F.S. had to install more than 35 000 m² of FIRE BARRIER 35 before the start of autumn. I.F.S used 60 workers and technicians. The general site organization consisted of teams for support cleaning, installing the mesh, fitting expansion joints, thickness rings, spraying-smoothing the mortar and removing the rings.

TUNNEL IMMERGE de BJORVIKA – PROTECTION AU FEU avec le FIRE BARRIER 135

A strict quality assurance plan was implemented with measurement of mesh attachment points, tear strength testing on anchorages (100 daN/unit), support spacing for the spacers and mortar thickness measurement. Samples of the mortar were also taken to measure its density, fire loss and compression strength. In situ adhesion tests were performed every week (on average, 4 times the customer's requirement).

The expansion joints have been subjected to joint research between Statens Vegvesen and INNOVATIVE FIRE SYSTEMS, to find a solution to all the problems of seals in an immersed tunnel.

- A waterstop with a maximum acceptable temperature of 80 degrees, with RWS constant fire exposure
- Assumed movement due to dilation is 3.5 cm in the middle of the tunnel.
- High pressure washing resistance is 150 bars

To meet customer requirements, IFS has developed an assembly of products withstanding 1400 degrees, composed of prefabricated and sprayed fire barrier 135.