

## EXPERTISE AS THE KEY TO OPTIMAL CHOICES

The construction of a tunnel demands enormous investment. But the investment could be worth its weight in gold. It's not for nothing that all over Europe stakeholders are prepared to upgrade existing tunnels and to make funds available for new tunnels below rivers, mountains or city centres. Examples are the train tunnels in the Alps and below the Channel, and the extension of metro tunnels in city centres in order to avoid traffic congestion. The economic value of this becomes apparent when an existing tunnel suddenly becomes unavailable. For example, this became painfully clear in the aftermath of the fire in the Mont-Blanc Tunnel. The regional economy of the Aosta Valley received a sharp blow when the tunnel was inaccessible for several years.



## RELIABLE SAFETY

The choice of two separate tubes, transverse connections... Eighty to ninety percent of the investment in tunnels is directly related to safety. Fire safety is a very important part of this. In this field a large number of choices are possible – with substantial consequences for safety and costs. Timely choices based on state-of-the-art knowledge can result in a safe tunnel, with robust and reliable safety systems, at an attractive level of cost. Nowadays, more and more contracts are of the form 'design, construction and maintenance'. Consequently the building contractor will select the party that can best demonstrate the ability to manage tunnel safety, availability and costs. Efectis supports customers in dealing with these factors down to the smallest detail.



Construction of a temporary tunnel for ad-hoc fire testing

## IMPRESSIVE LEVEL OF KNOWLEDGE

For decades Efectis has been building up an impressive position when it comes to knowledge in the field of fire safety in tunnels. This is for a large part due to its recent participation in large-scale European tunnel research programmes such as FIT, DARTS and UPTUN. Internationally, the Netherlands is a leading country in the area of tunnel safety. Nationally, the strict European Directive for tunnel safety is employed; Efectis however strives to exceed this.

Moreover, a representative of Efectis Nederland is a principal member of the technical committee of the NFPA 502 "Standard for Road Tunnels, Bridges and other Limited Access Highway".



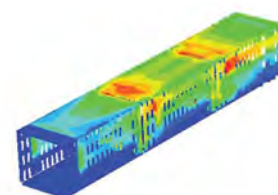
Full scale tunnel fire test with activated deluge fire suppression system

An example of Efectis' role as a leader is to be found in the so-called 'Rijkswaterstaat' (RWS) fire curve for the assessment of the strength of a tunnel structure. This assessment method was developed by Efectis in collaboration with the Dutch Ministry of Transport, Public Works and Water Management and is applied the world over, for example in regions such as Scandinavia, the Middle East, the USA and Singapore.

Clearly Efectis carries out not only testing and calculations according to existing procedures, but also designs relevant and cost-effective test methods. With this competence Efectis stands apart from others when it comes to advising customers about responsible investment in safety measures and achieving a high availability of the tunnel.



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CFD simulations of temperature development and fire behaviour of rolling stock during a fire in the Channel Tunnel

## CONSTANT KNOWLEDGE DEVELOPMENT

Efectis is closely involved in large-scale European fire tests in tunnels that aim to investigate the development and effects of severe fires. An example of such large-scale fire tests is the assessment of the effect of different extinguishing systems on the likelihood of explosion of a tanker during a tunnel fire. This is investigated in combination with the conditions that people might be exposed to in the direct wake of such a fire. This work has led to ground-breaking data that could be of importance when estimating the risk of a Boiling Liquid Expanding Vapour Explosion (BLEVE) during a tunnel fire.



*Tanker to assess BLEVE—risk in case of tunnel fire*

The development of knowledge at Efectis is a continuous process. For example, this is evident from the building of a temporary full-scale tunnel of seventy metres by eight metres on Efectis' site. Here, Efectis has carried out tests that have provided valuable insight into the working of new extinguishing systems. This insight will be re-worked into calculation tools for other applications.

## TRANSFER OF KNOWLEDGE



*Fire resistance test on tunnel door in front of the vertical furnace at Efectis Nederland*

Efectis doesn't keep the available knowledge to itself, but actively disseminates its tunnel expertise. Within the scope of 'Post Academic Education' we are able to transfer its knowledge. In addition, we develop and organise courses on the safety of underground infrastructure. Efectis' employees are also visible by way of presentations at international conferences and through the organisation of seminars. Our significant contribution to educational tours in Australia, China, the USA and Scandinavia serves as an example.

## TAILOR MADE SOLUTIONS AND ON TIME

It's clear that Efectis' knowledge is not only theoretical, but is also based on real-life tests and realistic projects. Nearly all of the large-scale tunnel projects in the Netherlands have been run through Efectis' computers, or the tunnel components have been tested on the furnace either at full-scale or in a scaled-down form. In addition Efectis has contributed to fire safety solutions within a large number of tunnel projects outside of the Netherlands. The power of Efectis lies in tailor made solutions. This knowledge based company designs an ideal mix of small-scale tests, large-scale tests, and simple or complex calculations for an optimal cost-effective solution. Furthermore, Efectis brings with it a flexibility that allows a relevant assessment to be made as quickly as possible.

## SAFETY SYSTEMS

Efectis' involvement in tunnel projects covers many roles and specialist areas. One such specialism concerns testing and evaluating fire safety systems and their effects. This involves, among other things, ventilators and ventilation regimes as an essential means for controlling fire, the spread of smoke and the possibilities for escape. In addition, Efectis is closely involved in testing new systems. Examples of this are advanced extinguishing systems based on oxygen depletion, sprinkler installations, water mist, compressed air foam and targeted extinguishing.



*Full scale fire test in progress in the TST test facility in Spain*

As far as fire safety measures are concerned the coherence of measures and systems is especially important. Two or more individually good systems can have mutually conflicting characteristics and effects. In combination such seemingly simple systems can suddenly exhibit unpredictable behaviour. That's why it's essential to test systems in combination. A good cohesion promotes not only the safety and cost management of a tunnel, but also the availability. A combination of individually good systems that is too complex can be error prone and lead to restricted availability over the whole tunnel. A rule of thumb is that simplicity and reliability are closely connected.

## THE ROLE OF COMPONENTS

Efectis understands the influence of building elements on the entire tunnel. Furnace tests with tunnel doors demonstrate how much heat gets through the door. This is of great importance when, for example, electrical installations are located behind the door. Also questions concerning aspects of the installation and insulation of electrical cabling hold no secrets for Efectis. In practice it all too often occurs that unexpected details counteract costly measures: 'the devil is in the detail' is a well-used phrase within Efectis.



*Exposed side of a tunnel segment after a fire resistance test. Spalling of concrete uncovered the reinforcement inside the concrete.*



## SAFE CONSTRUCTION – CONCRETE SPALLING & STRUCTURAL CALCULATIONS

Heat resistant lining is mostly intended to prevent concrete spalling - the breaking off of pieces - in the event of fire. Often the tunnel will survive the fire, but the amount of damage that the concrete structure has sustained probably remains unclear. Up until now the assumption has been made that the effect of a fire is limited to a depth of about ten centimetres - the rest of the structure remains un-affected by heat. Research undertaken by Efectis has clearly shown that cracking of concrete can also occur in these 'cold' parts of the tunnel. These cracks are found throughout the entire tunnel ceiling ranging from a depth of one to one and a half metres. The cracking takes place mostly in the parts of the structure where the mechanical load is greatest; these parts are essential for the load bearing capacity of the tunnel. This research, which questions the current practice, has been awarded a prize by the International Tunnelling Association (ITA/COSUF).



*Scale tests and computer simulations of cracking on the unexposed side of a tunnel structure after a fire. Research by Efectis has shown that during a tunnel fire cracks occur on the unexposed side of a submerged tunnel structure on the loaded parts. The cracks that occur during a fire do not disappear after the fire and can in general not be observed from within the tunnel, because the unexposed side is not visible or accessible. Various secondary effects of the cracks can cause a durability problem in the long term (degradation of the reinforcement)*

## MECHANICAL LOADING OF TUNNEL SEGMENTS

In order to incorporate the effect of spalling of concrete in a fire test it is very important that not only the test specimen represents the actual tunnel structure (i.e. same concrete mix, geometry), but also that the test specimen is subjected to realistic mechanical loading conditions. Efectis has a special loading frame that uses hydraulic jacks to create the actual loading conditions in an actual tunnel segment during the fire test. This frame enables the client to perform cost-effective and representative tunnel tests.

As of January 2017 Efectis has a second generation loading frame available with a massive loading capacity of 1000 tons.

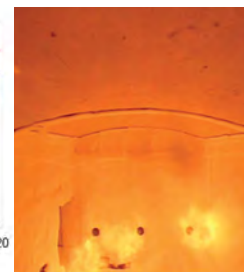
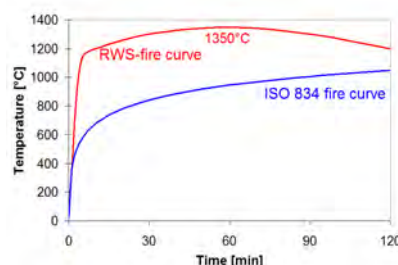


*Loading frame used for fire testing of bored tunnel linings*

## SAFE CONSTRUCTION - LININGS

An important area of work for Efectis concerns structural safety in all its forms. An example of such is insulation of the tunnel walls with fire resistant linings. The application of a thick layer of heat resistant lining is often possible, but is this always necessary? A special mix of concrete with additives such as polypropylene fibres can be used as an alternative, possibly in combination with a thinner layer of heat resistant lining.

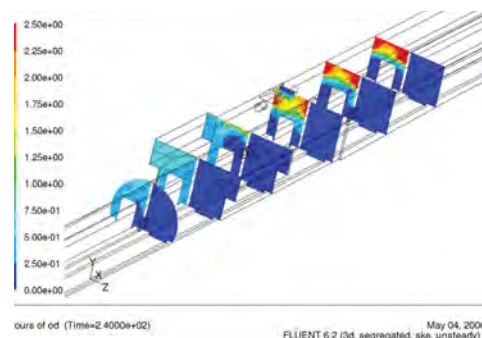
The simulation of plausible fire scenarios makes it clear which temperatures the tunnel wall will be exposed to during a fire, and which insulation material is appropriate for this. If the maximum temperature is not too high then cheaper solutions are possible. Efectis is one of the few companies in the world that is in a position to test to a maximum temperature of 1,350 degrees Celsius, in accordance with the Rijkswaterstaat (RWS) fire curve. It might be the case that the use of this curve is prescribed in a tunnel project. But, when there are no good reasons for using this curve, Efectis can argue for alternative fire scenarios and associated solutions, in consultation with the parties responsible for assessment. Such solutions may deviate from the current regulations, but they are indeed equivalent to them.



*The Rijkswaterstaat or RWS—fire curve, characterised by a very fast temperature development during the first minutes of the fire test and a high maximum temperature of 1350 °C after 60 minutes*

## PREDICTABLE SMOKE SPREADING

Computational Fluid Dynamics (CFD) calculations undertaken by Efectis contribute to several tunnel projects in terms of fire safety and cost savings. General starting points do not exist in this field. A practical example can make this clear: The 'Groene Hart' tunnel in the Netherlands makes use of longitudinal ventilation via shafts. Valves on the shafts were incorporated into the design. In the event of a fire these valves would close in order to allow a more effective working of the ventilation system. But CFD simulations that were undertaken by Efectis showed that in the absence of these valves the outcome would be at least as favourable. This meant a significant saving. Conversely, for a tunnel located in Rotterdam the CFD simulations showed that the valves indeed had an essential role. The question of timely evacuation of people forms an important component of the simulations. The latest scientific insights into the field of human (group) behaviour have been incorporated into the calculation tools.



*CFD simulations – smoke spread in the Groene Hart High Speed Line Tunnel*

## MOBILE FURNACE

Efectis is the first company in the world that is able to perform realistic fire resistance testing on-site using a mobile furnace. The brand name of the mobile furnace concept is the MobiFire, which stands for Mobile Fire Resistance. Efectis has developed two generations of the mobile furnace, which can follow any tunnel time temperature curve, including the RWS fire curve.



*Test tunnel segment on-site*

### Characteristics of the MobiFire service:

- Testing under realistic circumstances
- For existing structures the costs are reduced compared to a fire test in a laboratory
- Possibility to test immovable existing structures, such as monuments and tunnels
- New way of testing possible to select a cost-effective fire protection system
- For existing structures, no necessity of 90 days drying time of concrete slabs
- Easy testing of different alternative fire resistance solutions in real applications
- Avoid the cost of sending a team to witness a fire test

## ON-SITE TESTING

Efectis not only has facilities to test the performance of fire safety products and systems according to standards, but also has the possibility to perform on-site tests in existing real tunnels, at full-scale test facilities or any other desired location. We have easy access to the 600m long test tunnel at Tunnel Safety Testing (TST) in Spain, a state-of-the-art test tunnel fully dedicated to tunnel fire testing and fire fighter training. We have very good experience with the available support in manpower and infrastructure.



*The full scale tunnel on the TST site in Spain dedicated to all kind of tunnel fire tests*

Efectis has the means to perform in-situ tests (in tunnels, offices, high rise buildings...) related to smoke exhaust and ventilation systems.



- Mechanical smoke exhaust system testing
- Natural smoke exhaust system testing
- Full scale tunnel testing

## TRACK RECORD

The Efectis group has been involved in many tunnel projects throughout the world. Here we present a selection of these projects:

### RAIL TUNNELS

The Netherlands: Groene Hart Tunnel, Dordtse Kil Tunnel, Oude Maas Tunnel, Tunnel Rotterdam Noordrand, Botlek Rail Tunnel, Sophia Rail Tunnel. Others: Beveren Spoorunnel, Antwerp, Kennedy Spoorunnel, Antwerp (Belgium), Eurotunnel between France and UK, Crossrail tunnels in London UK, Marmaray tunnel in Istanbul, Turkey.

### ROAD TUNNELS

The Netherlands: Hubertustunnel in The Hague, IJtunnel in Amsterdam, Markt-Maastunnel in Maastricht, Roer-en Swalmentunnels in Roermond, Land tunnel A2 Leidsche Rijn in Utrecht, Westerscheldetunnel, Maastunnel in Rotterdam, Koningstunnel in The Hague. France: Tunnel du Foix, Maurice Lemaire Tunnel, Brotteaux-Servient Tunnel in Lyon, Saint Germain Tunnel (A14), Parette & Tilleuls tunnels in Marseille, Saint-Mandrier Tunnel, Road tunnel of Orly (RN7), Road tunnel of Mont Sion (A41), Road tunnel of Monaco. Others: Dublin Port Tunnel Ireland, Several tunnels in China and Singapore, Oresun Tunnel in Denmark, Tunnels on the M25 in London UK, Oosterweel-link in Antwerp in Belgium, Port of Miami Tunnel in Miami, US, Louis Hippolyte Lafontaine Tunnel, Montreal QC, Canada

### UNDERGROUND STATIONS

The Netherlands: Tramtunnel in The Hague, Statentunnel in Rotterdam, Noord Zuidlijn, Amsterdam  
France: TGV railway station of Chessy (77) in Disney Paris, TGV railway station of Massy, Underground station of metro in Strasbourg, Toulouse, Paris and Madrid.

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Efectis is the Expert in fire science, engineering, design and modelling, risk analysis, testing, inspection and certification.

Efectis covers all fire safety capabilities and know-how in testing and modelling around the world with offices and laboratories located in France, the Netherlands, Spain, Turkey, North Africa and the Middle-East area.