PROVISIONS AND MEASURES TO IMPROVE FIRE RESISTANCE OF TUNNEL STRUCTURES FROM THE POINT OF VIEW OF AN ACCREDITED TEST INSTITUTE

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ABSTRACT

Safety requirements in tunnels sometimes require a specification for fire resistance which cannot be fulfilled by concrete as built but has to be coated by protective layers. Time of fire resistance as a feature of concrete structure is strongly influenced by the chosen design fire. A comparison of different resistance periods as a function of the selected design fires (e.g. the ISO 834, the RWS curve and fire curves calculated from fire scenarios in particular tunnel geometries) are presented. This paper describes furthermore an overview about coatings and linings including concrete containing additives like fibrilised polypropylene fibers. Specific focus is placed upon the applicability of linings in existing tunnels regarding the improved performance against impact of temperature load. Experimental results about the temperature distribution as a function of depth within the concrete are given. Emphasis is put on the temperature as a function of time at the place of reinforcement for various thickness of the covering concrete layer.

Key words: Fire Loads, Fire Tests

The stepped-up occurrence of serious and even fatal fire accidents in traffic tunnels in Europe in recent years, has led to an increasing focus on safety aspects in tunnels. The extent of the damage caused to the concrete in the event of fire can be attributed to several damage mechanisms in the case of conventional concrete. The individual damage patterns are superimposed in most cases and can be split up into the following categories:

- vapour formations
- chemical transformations
- reinforcement failure
- thermal length alteration

Water acts in concrete in many different ways, but the harmful influences predominate. Water’s transition from liquid to gas at 100 °C is associated with a big energy intake. Apart from the energy intake during the transition phase from liquid to gas, there is a massive increase in volume, which is responsible for concrete parts flaking.

The rapid temperature increase causes spalling of the top layers of concrete with corresponding high humidity thereby setting free the first layer of reinforcement or removing the layer by layer of not enforced concrete. The temperature gradient moving into the concrete reduces step by step the strength and the distortion characteristics of the concrete and steel structure.

Less damage is to be anticipated from a small fire with a low energy build-up and a corresponding high porosity than in the case of a major fire involving compact concrete. The demand for a concrete with high strength and compactness, which seems justified for constructional reasons, in order to arrive a sufficient durability, emerges to be adverse in terms of fire resistance.
Fire Loads

As far as the assumed fire incident is concerned, so far very different fire load curves, which are used for tests, have been defined throughout Europe. In this connection, the duration of the individual phases and the absolute level of the temperatures arrived and depend on the nature of the combustible materials used. With regard to the temperature-time curves, this relates to the development of a fire and can be anticipated e.g. in dwellings or in commercial premises. This general curve course forms the basis for the fire load curve according to ISO 834 together with the “heating up phase”.

The considerably higher fire durations, amounting in some cases to more than 50 h, which were registered during the tunnel fire accidents in the last years, can be attributed to the flash-over point and the burning of different vehicles, which occurred at various times.

In order to dimension protective measures to counter fire loads, time-temperature curves are assumed, which in some cases, vary considerably from one another. Fires involving hydrocarbons, which are largely prevalent when a vehicle catches fire, are insufficiently represented by the course of the curve for the standard temperature curve – ETK. The heating up phase is reduced to a few min, once the maximum temperature is achieved. The other curves commonly used in Europe take this rapid increase into consideration.

![Temperature-time curves](image)

Figure 1: Temperature-time curves

The highest demands are placed in the Netherlands by the Rijkswaterstaat (RWS). The curve in question is based on a fuel tanker on fire in a tunnel. The exposed position of the Netherlands regarding tunnels in groundwater and with a large part of the surface of the country below sea-level has led to very high safety requirements governing the possible destruction of buildings, damage to which could have catastrophic results for the entire country.
Testing methods

There are only a few places throughout Europe where tunnel linings are tested. For clarification of occurring questions referring to the architectural fire safety the “Österreichische Straßenforschung” commissioned a research program for fire resistance of various concrete mixtures.

The objective is to reduce the spalling by additives of synthetic fibres and fibre mixtures. Further objective is to study the behaviour of mono stranded wire in case of a thermal load. This requires an estimation about the influence of the essential parameters (e.g. surface stress at the hot top layer, humidity, mineralogical composition of the addition, the classes of concrete resistance). As less heat load at the reinforcement shall be achieved in order to save the cross sectional load capacity as long as possible. Alternatively protective layers like panel linings, coverings, etc. which can be on still existing construction are investigated.

From the today’s point of view the test program includes 40 big sized plates of concrete which shall be exposed to the following heat loads:

Heat load according to RWS – curve
Heat load according to object specific fire curves
Heat load according to ISO 831

Size of concrete samples:

- 180 cm x 140 cm x 50 cm containing additional reinforcement in form of a net, thermocouples placed in various depths
- Various tension conditions at the hot side
- Samples with various humidity content due to different storage conditions
- Various compositions of concrete and synthetic fibre additives
- Stress-controlling reinforcement in different depth of the samples
Results

During fire tests carried out in the past at traditional conventional concrete, intensive spalling even in the initial phase has been observed.

Concrete devices containing particular additives have shown a totally different behaviour when exposed to the temperature load. Not any surface damages could be found by visual inspection after the test. The measured temperature values decrease in form of a steep gradient with increasing concrete depth. The temperature within the concrete raises with a time delay, even after stop of the temperature load. As deeper in the sample as later the maximum temperature value will be achieved.

Fire tests with fire board linings

Fire board linings have a protective effect by isolating properties against temperature load. It should be remarked, that the fire board linings are well suited to be installed in tunnels because they are designed to withstand and/or absorb bending stress, dynamic suction- and pressure forces caused by pressure- and suction-effects as a consequence of ongoing traffic.

Fire board linings must not be removed from the supporting concrete elements under high temperature conditions during a fire.

Fire board linings which have been tested in our Institute could prove appropriate behaviour in this point of view during the whole fire test.

Up to now a thickness requirement of 70mm was treated as state of the art. From today’s point of view it should be noted that nowadays, thanks to innovation, the thickness could be reduced to half of this value.

Fire resistance of construction products for the use in tunnels

All construction products used as tunnel equipment (e.g. fire resistant doors, closed service galleries for cables, etc.) which offer the class of fire resistance F 90 (“brandbeständig”) do fulfill 90 min of resistance if the ISO temperature load is applied. They do NOT resist 90 min if higher project specific temperature loads are applied or they fulfill resistance for a shorter time interval.

These lack of fire resistance has to be considered for fire barrier components as well. Their properties shall block the transfer of temperature and smoke, in particular to ensure a save escape of people in the first 30 min. Especially for the safety of people these components must fulfill the requirements for the whole of the specified time of resistance. Consequently those components have to be tested and have to prove their fire resistance properties for a temperature load which is realistic to be expected in the tunnel.

Conclusion

The real fire risk and the real temperature load resulting from the risk has to be the base for specification, design and approval procedure for construction parts.

In the initial phase of a fire the safe escape of persons present in the hazardous area is prior. The initial phase offering the possibility to escape is very limited in case of fires in a tunnel. Temperature exceeding 1000°C together with the smoke concentration provide conditions where the chance to survive is near zero. The surrounding walls in a tunnel together with the lack of heat escape in vertical direction lead to an intensive temperature increase in a few minutes.

Despite an innovative and successful progress in the field of construction parts numerous questions are still waiting for an answer. These questions have to be answered to meet the tunnel-specific safety objectives.

Beside the solution of technical questions the same intensive work has to be invested in test standards, classification standards and product standards in order to meet the reality best.