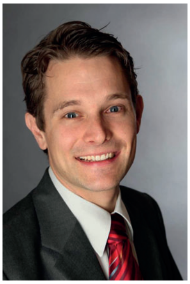
Tunnels under Fire – Higher Safety Due to Current FEM Practice

Ingo MÜLLERS
Civil Engineer, Dr. sc.
Schüßler-Plan
Düsseldorf, Germany
imuellers@schuessler-plan.de

Ingo Müllers, born 1976, received his civil engineering degree from the RWTH Aachen in 2002 and his PhD from ETH Zurich in 2007. He is currently head of the department in Advanced Structural Design with focus on accidental actions and dynamics.



Tobias BÖING
Civil Engineer
Schüßler-Plan
Düsseldorf, Germany
tboeing@schuessler-plan.de

Tobias Böing, born 1988, received his civil engineering degree from the RWTH Aachen in 2012. Since 2012 he is working as a civil engineer at Schüßler-Plan mainly involved in tunnel projects.

Summary

Tunnels are key elements in modern traffic networks. Therefore, potential consequences of their failure due to fire can be very high. A failure of a tunnel can lead to disproportionate cascade effects affecting the whole urban infrastructure system. Having this in mind, it is absolutely important to design tunnels against fire adequately. Hence, restraints due to thermal flux into the tunnel section, the effects of spalling of the concrete cover and decreasing material resistance of concrete and reinforcement have to be considered during the calculation. The authors show how tunnels can be designed taking all these circumstances into account by using modern FE-codes. The design procedures are conducted following strictly the existing codes (Eurocodes 1 and 2). Furthermore, it is shown that today plane as well as spatial structure subjected to fire can be analysed adequately.

Keywords: Tunnel, fire, fire design, reinforced concrete, FEM.

1. Introduction

The aim within the design of tunnel structures against fire is clearly more elaborate compared to the design against regular loading because a thermal and a mechanical analysis of the structure have to be combined. Years ago this combination was not possible and the structural safety in a case of fire was demonstrated by a pure thermal analysis, i.e. it was demonstrated that the temperature of the reinforcement does not exceed a certain value. Today, due to modern FE-codes structural engineers are able to conduct a thermal and a mechanical analysis using a combined calculation procedure. Therefore, restraints and decreasing material resistance due to thermal flux into the concrete section can be modelled realistically.

The presented paper explains the state-of-the-art of fire design in tunnels in accordance with Eurocodes 1 and 2. In order to do this, current FE-codes are used and plane as well as spatial tunnel models are examined. Finally, the paper shows how a structural analysis against fire in tunnels can be conducted, what are the advantages compared to other more simplified methods and how typical results look like.

2. Performance of structures subjected to fire

In contrast to the regular design of reinforced concrete tunnel structures three additional physical phenomena have to be taken into account during the design procedure against fire:

- Restraints within the structure caused by thermal flux into the tunnel section,
- Spalling of the concrete due to high temperature,
- Decreasing material resistance and stiffness due to high temperature.

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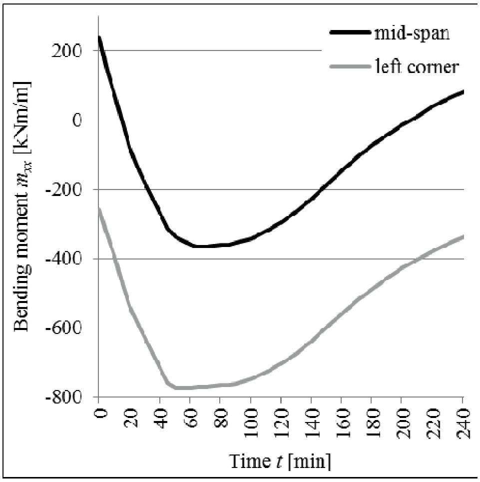
3. Plane and spatial tunnel models



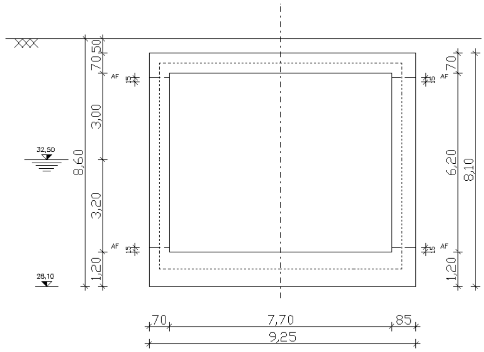


Fig. 1: Cut & Cover tunnel (right), Moment-time-relation during a fire (left)

One investigated plane tunnel is a road cut and cover tunnel made out of reinforced concrete (see figure 1).The tunnel was verified by using the general design procedure. This means that a thermal and a mechanical analysis are conducted consecutively. In order to check the reasonableness of the results, the development of the bending moments over time of the tunnel ceiling are represented (see figure 1). It is demonstrated that the bending moments become more negatively during a fire. This is plausible because the inner surface of the tunnel tries to elongate but it is restrained by the hyperstatic structure itself.

The final objective of the investigation was to model a spatial tunnel structure. Therefore, a tunnel portal with large spans (22,25 m and 25,18 m) was described (see figure 2). The tunnel portal is a reinforced concrete structure with huge load bearing walls at the portal.

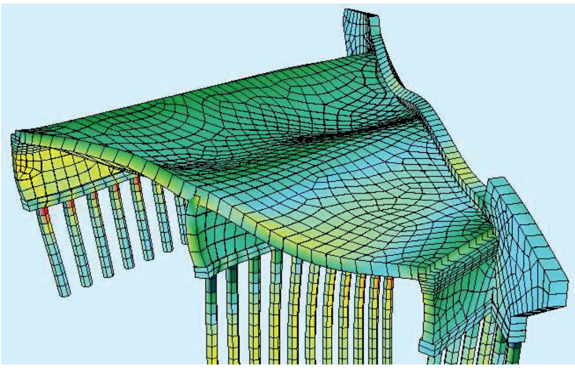


Fig. 2: Deformed tunnel portal due to fire (deformations superelevated)

In a first step only the reinforcement of the regular design situations was used to verify the tunnel structure against fire. Afterwards, the reinforcement was stepwise increased until the structure has been at equilibrium during the whole calculation time.

The plausibility of the results was not only checked by deformations or bending moments but also by using plane models of important parts of the tunnel structure. Using this model it was shown that even complex spatial structures can be designed accurately against fire.

4. Conclusion

The described investigation shows that modern FE-codes are able to model the structural behaviour of tunnels even under fire. Structural engineers are able to predict the structural safety of tunnels subjected to serve fires taking into account the following circumstances: plane or spatial tunnel structure, spalling of the concrete cover, restraints and decreasing material resistance as well as stiffness. Regarding the assessment of existing tunnel structures, the general design methods enable engineers to verify the structural safety by taking into account exactly the condition of the existing structure.