Structural Safety Assessment of Tunnels subjected to Fire Loading

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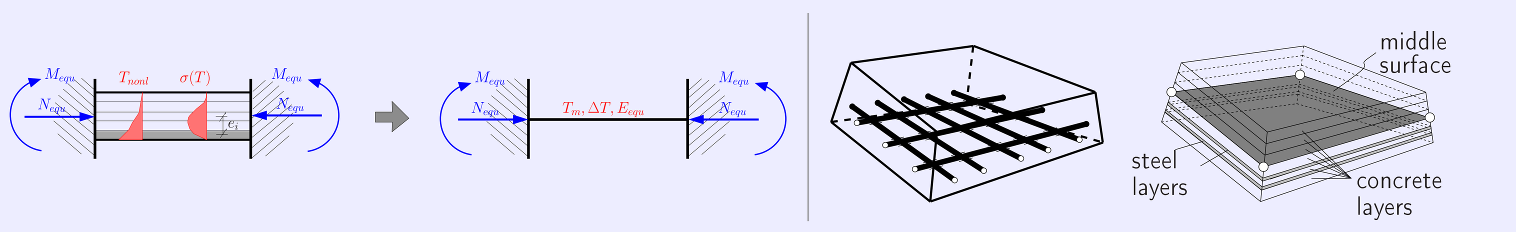
Tunnel cross-sections are investigated applying different material models and modes to consider fire loading (equivalent temperature loading and nonlinear temperature distribution). The influence of spalling and the effect of combined thermo-mechanical loading (known as LITS) on the numerical results is illustrated.

Motivation

Tunnel structures have to fulfill requirements as regards their bearing capacity and serviceability before as well as during/after fire accidents. In engineering practice, the determination of the structural safety of tunnels subjected to fire loading is based on the so-called equivalent-temperature concept, assuming linear-elastic material behavior. The equivalent temperature load is calculated by setting equal the respective stress resultants within a clamped beam with the stress resultants generated by the real (nonlinear) temperature distribution.

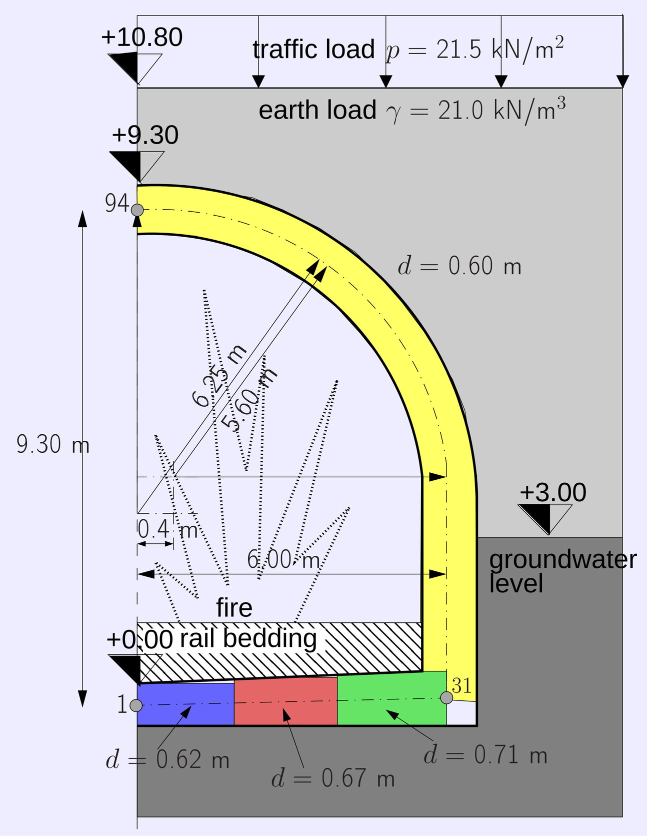


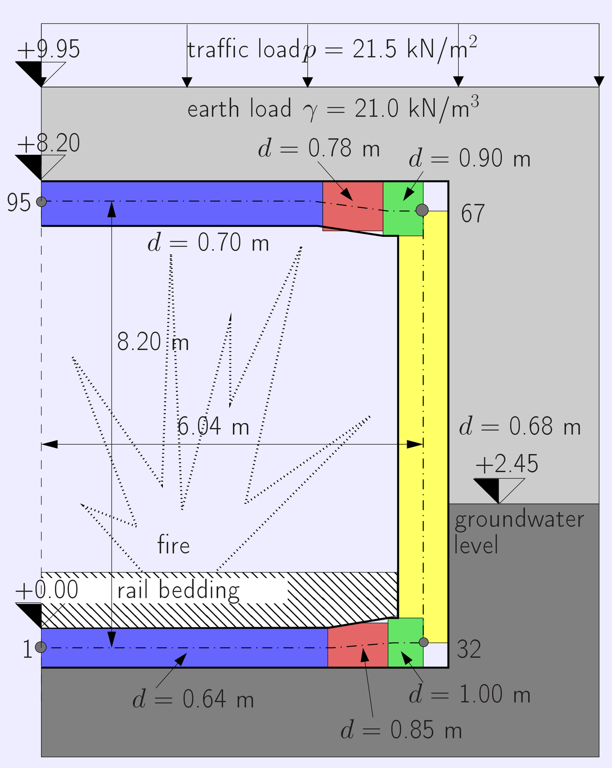
These model assumptions represent simplifications of reality and therefore introduce deviations from the real behavior of the structure. In this work, the influence of the following parameters on the structural behavior of tunnels under fire loading is investigated: (i) different modes to consider fire loading (equivalent temperature loading or nonlinear temperature distributions), (ii) spalling, and (iii) combined thermo-mechanical loading by introduction of load-induced thermal strains (LITS). Hereby, thick layered shell elements are employed, enabling for (i) assignment of different temperatures and, hence, of temperature-dependent material parameters to the respective layers and (ii) consideration of spalling by de-activation of the respective near-surface layers.

Model Parameters

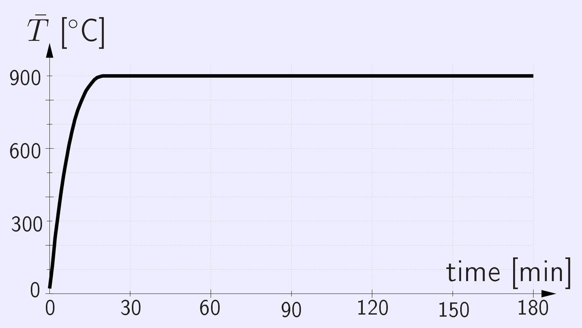
A circular and a rectangular double-track railway tunnel cross-section are investigated. In addition, different spalling scenarios are considered, with a final spalling depth d_s^∞ [m] to be reached after 30 min of fire loading (with $d_s^\infty = 0$, and 0.2 m). Furthermore, different material models and modes to consider temperature loading are employed:

- Linear-elastic material behavior and equivalent temperature (LE, no LITS – T_m, ΔT),
- Linear-elastic/ideal-plastic material behavior without consideration of LITS and nonlinear temperature (LE/IP, no LITS – T_{nonl}), and
- Linear-elastic/ideal-plastic material behavior with consideration of LITS and nonlinear temperature (LE/IP, with LITS – T_{nonl}).



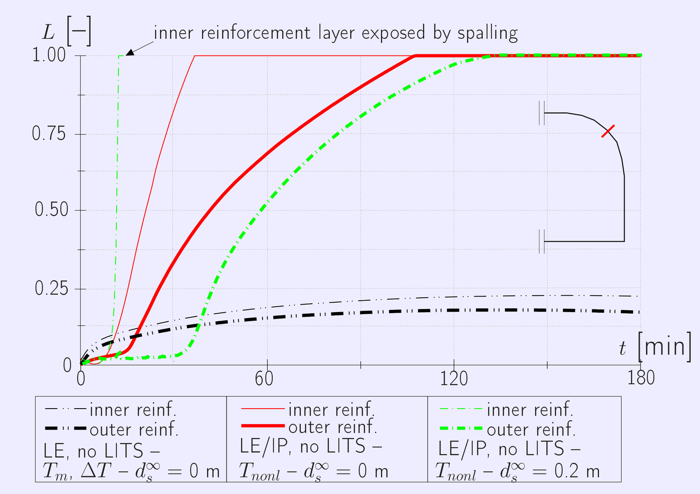


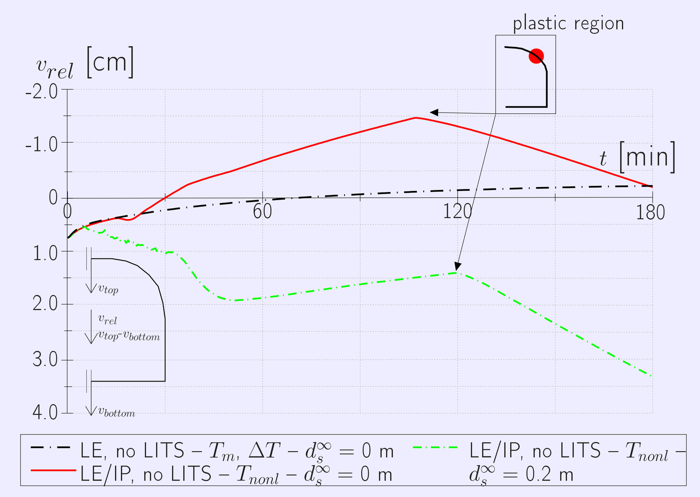
The bottom of the tunnel is covered by a gravel layer as rail bedding which is considered to protect this part of the tunnel structure from fire loading. Therefore, temperature loading (representing a fire of stacked car tires) is applied only at the side wall and the top of the tunnel. The duration of the fire load is set to 180 min with an increase of the surface temperature up to 900°C within the first 20 min.

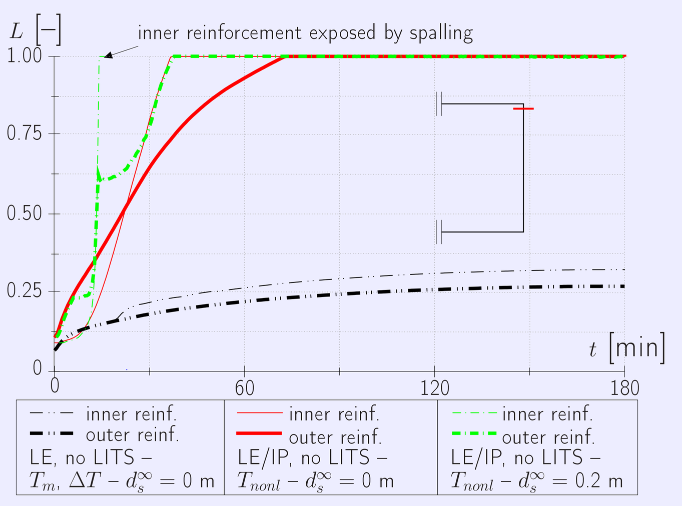


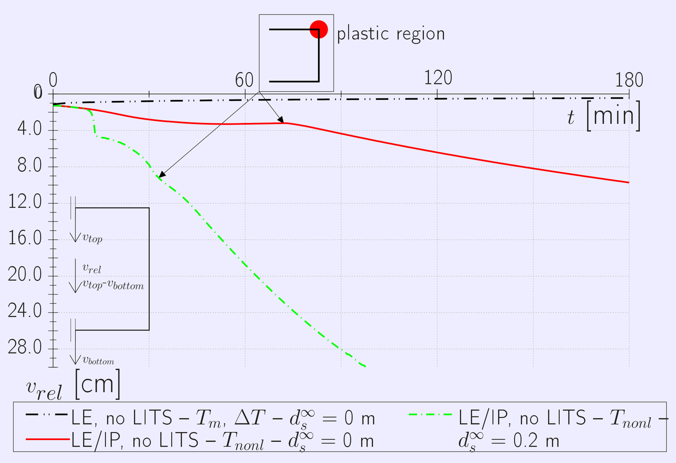
Results

The numerical results exhibit a large sensitivity to the material model and mode to apply temperature loading. In case of linear-elastic material behavior plus equivalent temperature (LE, no LITS – T_m, ΔT), the level of loading of the steel reinforcement (i.e. the ratio between stress and temperature-dependent yield strength) is considerably smaller than in case linear-elastic/ideal-plastic material behavior plus nonlinear temperature distribution (LE/IP, no LITS – T_{nonl}) is considered. In the latter case, $L =$ 100% is observed, indicating the formation of a plastic hinge at the shoulder/upper corner of the cross-sections. The development of a plastic hinge is also visible in the evolution of deformations which increase as plasticity occurs. The deformations are also greatly dependent on the considered material model with more realistic displacements for LE/IP, no LITS – T_{nonl}. When spalling is considered, the compliance of the tunnel is further increased, leading to larger displacements. Comparison of the two investigated cross-sections shows a higher structural safety (i.e., smaller deformations) of the circular cross-section which a more pronounced difference when spalling is considered.

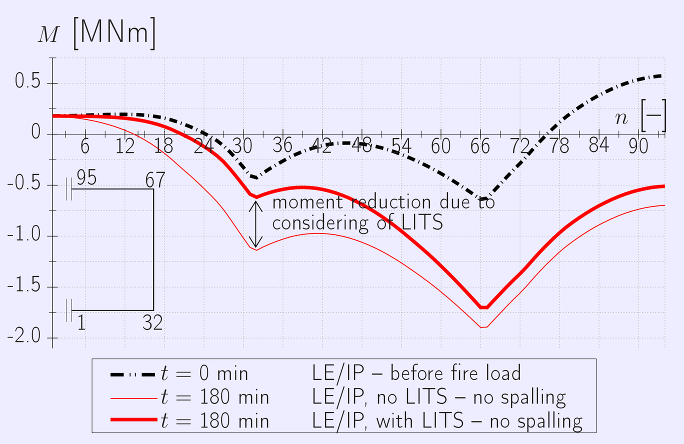


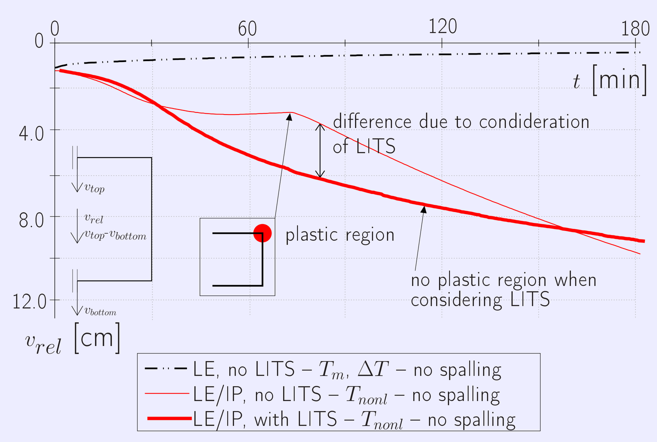






The introduction of LITS in order to account for combined thermo-mechanical loading leads to a reduction of the restraint in consequence of hindered thermal expansion and therefore to smaller magnitude of stresses and, thus, bending moment. This reduced restraint also has an effect on the occurrence of plasticity within the steel reinforcement, changing the evolution of deformations significantly.





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