1. Introduction

Recent fire hazards, especially in tunnels, were characterized by severe damage of the support structure, resulting from spalling of near-surface layers and thermal deterioration of the remaining lining material, significantly reducing its load-carrying capacity. Within the research project “Safety of underground structures under fire loading”, a numerical tool shall be developed allowing the realistic prediction of the remaining load-carrying capacity of concrete structures subjected to fire. This tool is validated by especially designed large-scale experiments, focusing on the redistribution of loading within the structure in the course of fire loading.

2. Design

In order to capture the redistribution of loading within the structure, a frame-like structure (as opposed to commonly employed circular cross-sections), was designed for the fire experiments (see Fig. 1(a), [1]). This frame was loaded mechanically by steel elements with a total load of 39 kN, in order to simulate the overburden. In total, four frames (two made of concrete with 1.5 kg/m³ polypropylene (PP-)fibers and two without PP-fibers) were tested. The fire load was applied at the inner surface of the frame by means of two oil-burners (see Fig. 1(b), only the side wall and ceiling of the frames were thermally loaded, whereas the bottom was insulated) following a pre-specified temperature history. The fire load was applied for 3 h, with a maximal temperature of 1200 °C reached after 15 min and held constant till the end of the experiment. During casting of the concrete frames, temperature sensors (see Fig. 1(c)) were positioned at different sections and depths in order to obtain the temperature evolution within the cross-section. The furnace temperature was monitored by seven temperature sensors pointing into the furnace.

3. Experimental results

A large amount of information was obtained during the large-scale fire tests (for more results, see [1]). In the following, selected results are presented.

The deformations and rotations of selected points were permanently monitored during the experiment. In Fig. 2 the history of the vertical displacements at mid span of the frame is shown.

Fig. 1: (a) Experimental setup, (b) oil burners, (c) placed temperature sensor
From the results, the development of a bulge of the ceiling of the frame in longitudinal direction can be observed, since points in the symmetry axis and points on both side faces were monitored. The bulge reaches almost 20 mm over a length of 2 m from side to side.

In addition to the deformations, also the rotations of the corners of the frame were monitored, giving access to the evolution of cracks in the frame corners.

Since different concrete mixtures were investigated (concrete with and without PP-fibers significantly influencing the spalling behavior), the extent of spalling was monitored during the experiment (see Fig. 3).

For this purpose, acoustic sensors were used to record the spalling intensity. The sound level measured for different frequencies gives access the time and extent of spalling.

After the experiment, the final spalling depth was measured (see Fig. 4(a)). For concrete without PP-fibers, a final spalling depth up to 7 cm was reached, leading to exposition of the inner reinforcement layer to fire. In addition to final state of spalling, the location of cracks and the crack width were recorded after the experiment (see Fig. 4(b)).

The obtained data from the large-scale fire experiments provide the basis for proper validation of the anticipated numerical analysis tool (see [2]), incorporating nonlinear effects of concrete at high temperatures stemming from physical and chemical processes within the cement paste and aggregates as well as redistribution of loading at the structural scale.

4. Acknowledgments

This research was conducted with financial support by the Austrian Ministry for Transport, Innovation and Technology (bm.vit) within the KIRAS-project (Austrian security research program) 813794 "Sicherheit von Hohlraumbauten unter Feuerlast" ("Safety of underground structures under fire loading").

5. References
