LARGE-SCALE FIRE TESTS ON CONCRETE – DESIGN AND RESULTS

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In order to improve the safety of underground infrastructure such as tunnels, the behavior of reinforced-concrete structures subjected to fire loading is investigated by means of large-scale fire experiments. The goal of these experiments is to gain valuable data for the assessment of numerical tools commonly used for the analysis of the load-carrying capacity and the design of underground support structures subjected to fire.

Design of experiments

Experimental setup:
In order to capture the redistribution of loading within reinforced-concrete structures, a frame-like structure (as opposed to commonly employed circular cross-sections) was designed for the fire experiments (see Fig. 1, [1]). This frame was loaded mechanically by steel elements with a total load of 390 kN in order to simulate the overburden. In total, four frames (two made of concrete with 1.5 kg/m^3 polypropylene (PP-)fibers and two without PP-fibers) were tested. The fire load was applied at the inner surface of the frames by means of two oil-burners following a pre-specified temperature history (see Fig. 2, only the side wall and ceiling of the frames were thermally loaded, whereas the bottom was insulated). The fire load was applied for 3 h, with a maximal temperature of 1200 °C (see Fig. 3).

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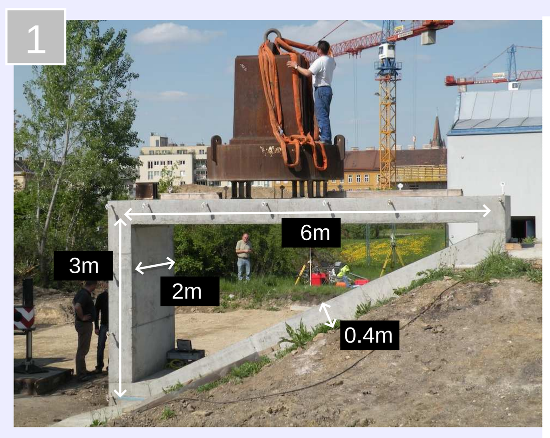

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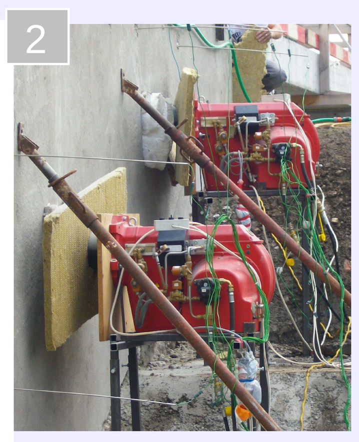

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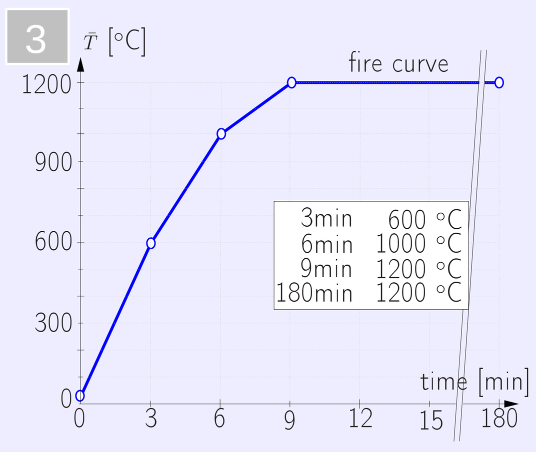

- **Temperature measurement:**
  Six temperature-measuring elements (see Fig. 4) were positioned at different sections. Within these precast elements, temperature sensors were placed at various depths (0.3, 1.0, 2.0, 4.0, 6.0, 8.0, 10.0, 20.0, 30.0 cm) in order to obtain the temperature evolution within the cross-section. The furnace temperature was monitored and regulated by seven temperature sensors pointing into the furnace.
- **Deformation and rotation measurement:**
  The optical displacement measurement was done at 31 measurement points (see Fig. 5). Three rows of measurement points were distributed over the frame, giving access to deformation and bulge of the cross-section. A representative measurement point is presented in Fig. 6, showing a measurement mirror and its heat protection. The rotations were recorded at every corner of the frame by means of inclinometers.
- **Acoustic measurements:**
  In addition to temperature and deformation/rotation measurements, acoustic measurements were performed in order to gain access to the evolution of spalling (i.e., reduction of the cross-sectional area). For this purpose, acceleration sensors recording the sound level for a certain range of frequences (20-16000Hz) were used.

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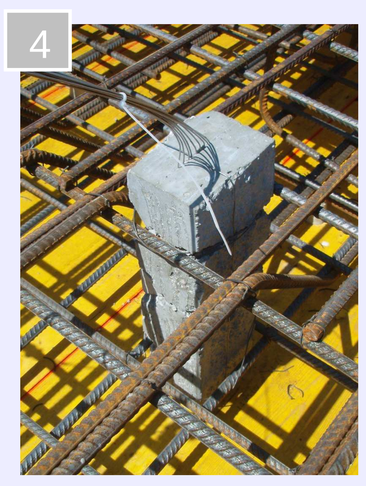

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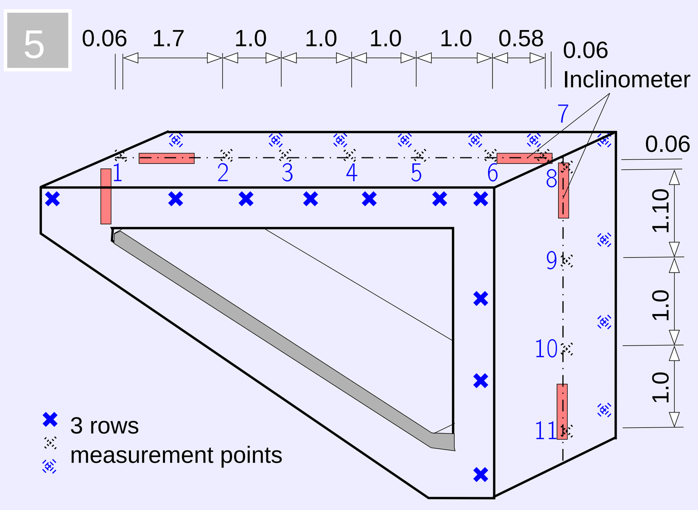

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Acknowledgments

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Experimental results

Temperatures:
Fig. 8 shows the temperature history at the seven measurement points located within the furnace. Due to spalling of near-surface concrete layers, the prescribed fire curve was reached after 40 min of testing. Measurement points 11 and 24 show lower temperatures which is explained by spalled-off pieces of concrete covering the temperature sensors.

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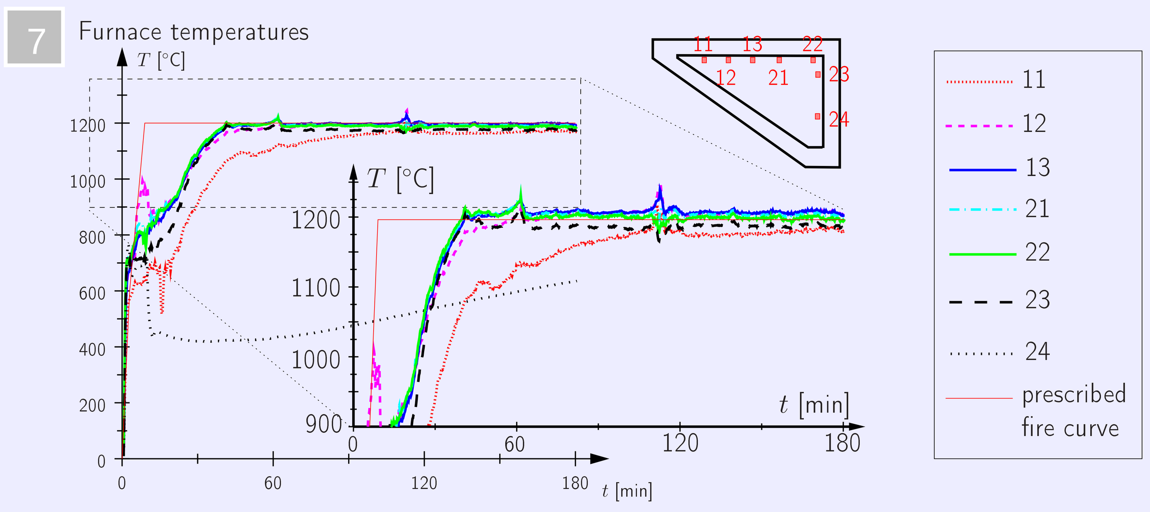

Deformations:
Fig. 9 shows the history of the vertical displacements at the mid span of the ceiling of the frame. As indicated by the measurement data, a bulge of the ceiling develops along the longitudinal direction. This bulge reaches almost 20 mm over a length of 2 m from side to side. Fig. 10 contains the deformations in the symmetry plane, showing the largest deformation in the middle of the ceiling (below the mechanical load).

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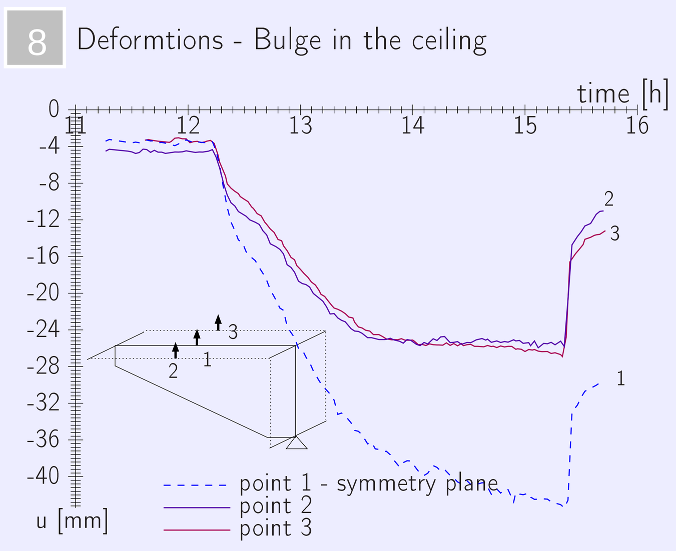

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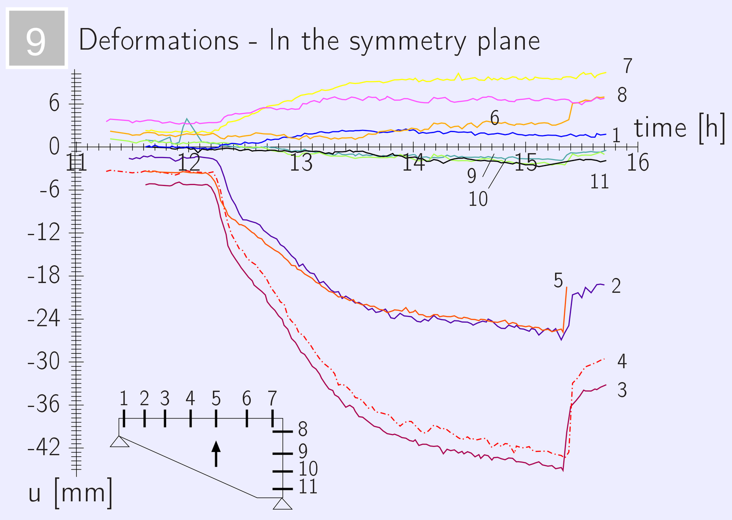

Spalling and cracks:
Since different concrete mixtures were investigated (concrete with and without PP-fibers, with significantly different spalling behavior), the extent of spalling was monitored during the experiments with acceleration sensors (see Fig. 11). After the experiment, the location of cracks and the respective crack widths as well as the final spalling depth were recorded. 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 (see Fig. 13).

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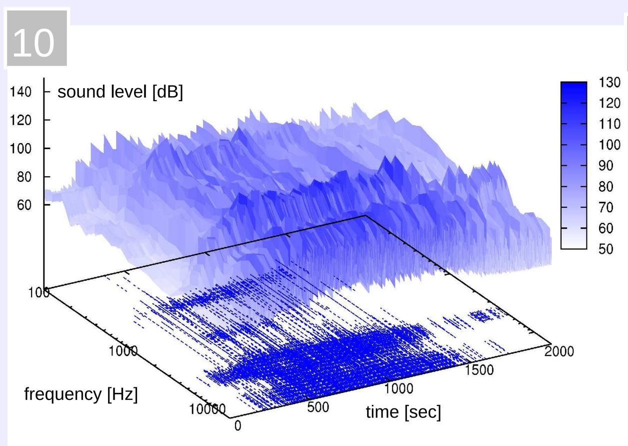

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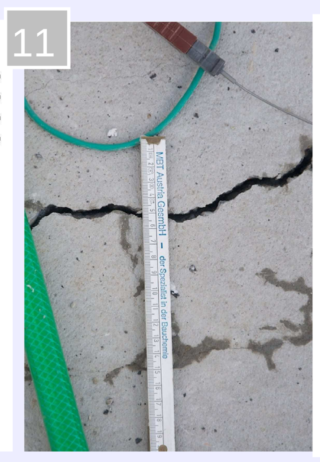

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The data obtained from the presented large-scale fire experiments provide the basis for the proper validation of tools for the analysis of reinforced-concrete structures subjected to fire (see, e.g., [2]).

References

[1] T. Ring, M. Zeiml, and R. Lackner. Underground concrete frame structures subjected to fire loading: Part I – large-scale fire tests. *Engineering Structures*, 2011. In preperation.

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