On a hybrid simulation using a phase-field approach for predicting the concrete behavior under fire

Chaitanya Kandekar*[1], Max Rottmann[1], Arulnambi Palani[2], Michael Breuer[2], and Wolfgang E. Weber†[1]

[1]Chair of Structural Analysis, Helmut Schmidt University/ University of the Armed Forces, Hamburg, Germany – Germany

[2]Chair of Fluid Mechanics, Helmut Schmidt University/ University of the Armed Forces, Hamburg, Germany – Germany

Abstract

Concrete exhibits a highly non-linear material behavior, especially under non-isothermal conditions like fire exposure. At elevated temperatures, the interaction between heat and mass transfer can lead to a specific mode of concrete degradation, also called thermal spalling, affecting substructural components such as walls and columns. Spalling can be explosive, resulting in a substantial reduction in the load-bearing capacity at structural scale such as buildings. Extreme temperature gradients and moisture clogs play an important role in understanding the cracking and subsequent spalling of the fire-exposed substructural concrete components. Recently, the phase-field method has been proposed to address this challenge and simulate fire-induced concrete spalling (1). This approach facilitates a straightforward numerical setting to simulate complicated phenomena at the component level, e. g., the initiation and development of cracks. Drastic reduction in the load bearing capacity of one substructural component results in a redistribution of the internal forces and coordination of deformations between all substructures. Furthermore, simulations of the structural scale necessitate damage simulations of each component and a computational framework, which can deal with scale transition during fire-structure interactions. However, simulating these multiphysics phenomena at structural scale is numerically very challenging.

The objective of this contribution is to provide a computational framework for fire-structure simulations to elucidate the interplay between local damage of the concrete due to fire and its effects on load-bearing capacity on the building scale. In this simulation framework, the temperature distributions and the evolution of the fire exposed components are taken from the simulation results of the real fire scenario using the open-source software *Fire Dynamics Simulator* (2). It is a computational fluid dynamics code relying on the large-eddy simulation technique to account for the instantaneous turbulent flow and heat transfer including combustion and radiation. Furthermore, the substructural model treats concrete components as a porous material locally exposed to the fire, whereas the structural model simulates load-bearing capacity on the building scale. Thus, in the proposed computational setup, two additional softwares are used to simulate material damage and the resulting load redistribution of an exemplary structure under fire. The substructural-scale model uses a *FEniCS*-based solver for the concrete material. Herein, the concrete damage such as cracks

*Speaker

†Corresponding author: wolfgang.weber@hsu-hh.de

and subsequent spalling is computed using a unified phase-field method. The structural-scale model uses *ABAQUS* for mechanical simulations. These solvers exchange information on the damage and the resulting changes in geometry across scales through the open-source coupling library *preCICE* (3). The proposed model is illustrated by an example case that forecasts the fire-induced damage caused by the thermal spalling of the concrete substructure and its effects on the global scale.

References:

1. P. Cheng, H. Zhu, Y. Zhang, Y. Jiao, J. Fish: Coupled thermo-hydro-mechanical-phase field modeling for fire-induced spalling in concrete. Computer Methods in Applied Mechanics and Engineering, vol. 389, 114327, 2022.

2. K. McGrattan, R. McDermott, C. Weinschenk, G. Forney: Fire dynamics simulator technical reference guide, sixth edition. NIST Special Publication 1018, National Institute of Standards and Technology, 2023.

3. G. Chourdakis, K. Davis, B. Rodenberg, M. Schulte, F. Simonis, B. Uekermann et al.: preCICE v2: A sustainable and user-friendly coupling library. Open Research Europe, vol. 2, no. 51, 2022.