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NUMERICAL ANALYSYS OF SPALLING OF CONCRETE COVER AT HIGH TEMPERATURE

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ABSTRACT

When temperature increases for a couple of hundred of degrees Celsius, behaviour of concrete changes significantly. The concrete mechanical properties, such as strength, elasticity modulus and fracture energy, are at high temperatures rather different than for the concrete at normal temperature. At high temperature large temperature gradients lead in concrete structures to temperature-induced stresses, which cause damage. Furthermore, creep and relaxation of concrete that is due to high temperature play also an important role. The main reason for the complexity of the behaviour of concrete at high temperature is due to the fact that concrete contains water, which at high temperature changes its aggregate state and can generate significant pore pressure. Although the behaviour of concrete at high temperature is in the literature well documented [1], further experimental and theoretical studies are needed to clarify the interaction between hygro-thermal and mechanical properties, such as for instance explosive type of failure due to spalling of concrete cover.

In the present paper a three-dimensional (3D) model, which is based on the thermo-hygro-mechanical coupling between thermo (temperature), hygro (moisture and pore pressure) and mechanical properties of concrete is discussed. The model is formulated in the framework of continuum mechanics under the assumption of validity of irreversible thermodynamic [2]. The response of the model is controlled by the following variables: temperature, pore pressure, stresses and strains. Temperature, moisture and pore pressure are coupled with stresses and strains, i.e. thermo-hygro part of the model depends on damage of concrete. Moreover, the relevant mechanical properties of concrete (tensile strength, compressive strength and fracture energy) are temperature dependent.

In the mechanical part of the model the temperature dependent microplane model [3] is used. The total strain tensor for concrete exposed to high temperature is decomposed into mechanical strain, free thermal strain, thermo-mechanical strain and strains that are due to the temperature dependent creep of concrete. Furthermore, the microplane model

parameters are made temperature dependent such that the influence of temeperature on the mechanical properties of concrete (tensile and compressive strength and fracture energy) is accounted for.

The presented thermo-hygro-mechanical model for concrete is implemented into a 3D finite element code, which was used in the study of explosive spalling of concrete cover. The performed numerical analysis is incremental. In each time step Δt simultaneously are solved partial differential equations, which control heat and moisture transfer in concrete, and equation of equilibrium (mechanical part of the model). It is assumed that in each time step damage is constant, i.e. thermo-hygro properties of concrete are controlled by damage parameter from the end of the previous time step.

To check the model and its implementation into the finite element code, a theoretical example from the literature [2] is analyzed. The comparison of the results confirmed that the model and its implementation are correct. Subsequently, 3D FE analysis of spalling of concrete cover was carried out. In the analysis a concrete slab was heated locally at a free surface. It is studied the influence of the hygro-thermo-mechanical properties on spalling of concrete cover. Tensile strength, initial porosity, permeability and moister content were varied. Moreover, it was investigated whether the geometrical instability has a significant influence on the spalling of concrete cover.

The numerical results indicate that the pore pressure, which is mainly influenced by permeability of concrete, have the strongest influence on spalling of concrete cover. The influence of geometrical instabilities due to compressive stress seems to be of minor importance.

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