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Thermo–hygro–mechanical modelling of self-induced stresses during the service life of RC structures

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ABSTRACT

Current practices of structural design in reinforced concrete (RC) structures usually account for stresses caused by phenomena such as heat of hydration and drying shrinkage in a quite simplified manner. The present paper aims to evaluate the consequences of explicitly considering self-induced stresses, which actually vary significantly within structural cross-sections, combined with stresses caused by external loads. The used numerical framework involves the explicit calculation of the temperature field in concrete, with proper account for the heat of hydration of cement. Simultaneously, the moisture field in concrete is computed in order to ascertain the relative humidity changes in the pore structure caused by drying, and the inherent shrinkage strains. Stress calculations are made with due consideration of the evolution of mechanical properties of concrete as a function of the equivalent age, as well as relevant phenomena like creep, concrete cracking and influence of reinforcement. Two separate groups of numerical applications are presented, checking influence of the self-induced stresses: a unrestrained concrete prism usually used for shrinkage measurement, and concrete slabs subjected to external loads. Particularly for the second set of applications, the obtained results (with explicit consideration of the differential effects of self-induced stresses) are compared, in terms of cracking loads and crack propagation, to those that would be obtained by using the simplified design approach based on considering uniform shrinkage fields in concrete. It is found that the behaviour of both formulations is quite similar after crack stabilization, but may be quite distinct in the crack propagation phase.

1. Introduction

The existing methodologies for practical analysis and design of RC structures comprise several simplifying assumptions, namely concerning the stress state induced by heat of hydration and drying shrinkage. Actually, due to the exothermic nature of cement hydration reactions, concrete members endure non-uniform internal temperature distributions, usually with hotter regions in the core and cooler ones close to the external surfaces. Total or partial restrictions to the volumetric deformations associated to these thermal fields induce stresses in concrete, whose importance is usually disregarded by designers, most of the time without a quantitative notion of their magnitude. Their quantification is, however, possible with recourse to thermo–mechanical methodologies that allow the computation of temperatures induced by heat liberation, and using them as thermal loads in the numerical simulation of stress fields.

Regarding drying shrinkage, and according to code provisions [1,2], its structural effects are taken into account by using reference shrinkage strains (based on the geometry of the concrete member, environmental relative humidity and concrete grade class), which thereafter are applied uniformly to the structure in order to ascertain the corresponding stresses. This is clearly a simplification for practical calculations, since drying occurs non-uniformly in concrete, which generates stresses in the presence of restraints (which are external, caused by reinforcement or due to cross-sectional effects). The quantification of the differential drying shrinkage calls for the necessity of knowing the moisture fields within concrete, as well as the relation between moisture losses and the corresponding volumetric variations. Since most generally RC structures suffer effects of both heat of hydration and drying shrinkage, it is important to have numerical simulation tools that allow the computation of thermal, moisture and mechanical fields for the computation of stress states during the service life.

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