Modeling of Viscoelastic Phenomena in Concrete Structures

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Abstract

A growing demand is recently emerging of sensors to be integrated in the concrete in order to measure some critical parameters, such as humidity and temperature and the internal pressure of the material. For example, by monitoring the pressure in various strategic points of the structure and their evolutions over time it is possible to understand the health of the structure and the needs for maintenance intervention.
The modeling of viscoelasticity is one of the most relevant challenges for a reliable analysis of a concrete structure and its embedded sensors.
COMSOL Multiphysics®, thanks to its strong multiphysics capabilities, is particularly useful for modeling any kind of sensor functionality. Being able to use COMSOL also to model concrete peculiarities and in particular its viscoelasticity characteristics would provide a complete tool for reliable simulations of various types of sensors in concrete structures.

Even if COMSOL software has built-in solutions for the modeling of viscoelasticity, concrete peculiarities suggested developing an ad-hoc model. Actually, the elective mathematical model for concrete viscoelasticity is based on Kelvin chains. COMSOL flexibility has allowed building a brand new mathematical model, exploiting equation-based modeling capabilities.
The generalized Kelvin model consists of an elastic spring to represent the instantaneous stiffness plus n Kelvin-Voigt branches connected in series. The creep function results in a linear combination of exponential terms.
We used, in particular, 8 Kelvin branches to model the concrete viscoelasticity. The model could then calculate viscoelastic effect by solving the strains in the viscoelastic branches with the Domain ODEs and DAEs interface.

The model was compared with viscoelastic creep of concrete obtained from theoretical model [1], showing a perfect agreement (Figure 1).
The model was then used for studying the effect of concrete creep on an embedded sample of silicon, with a membrane, that could represent a simplified sensor structure for pressure measurements (Figure 2). A constant pressure load of 10MPa was applied on top of the concrete cylinder. We used the Structural Mechanics Module to develop our model.
We could demonstrate that concrete viscoelasticity profoundly modify the membrane displacement over time, even if a constant load is applied (Figure 3).
The strain increase effect is even amplified if we take into account another typical concrete phenomenon, which is its shrinkage, mostly due to a loss of humidity over time. The

additional effects of the shrinkage strain and of the viscoelasticity are represented in Figure 4.

This work demonstrated COMSOL flexibility in modeling materials properties using ad-hoc mathematical models. Results on concrete samples demonstrated very satisfying agreement. They allowed a preliminary evaluation of the effects of concrete viscoelasticity (combined with other particular phenomena such as shrinkage strain) on the functionality of a sensor structure.
Our studies, then, pave the way to a fruitful exploitation of COMSOL software in the modeling of new sensors even in those special environments in which dedicated and brand new mathematical models are required to describe some relevant phenomena.

Reference

[1] “Model Code 2010, Final Draft, Volume 1” and “Model Code 2010, Final Draft, Volume 2”, fib Bulletin No. 65

Figures used in the abstract

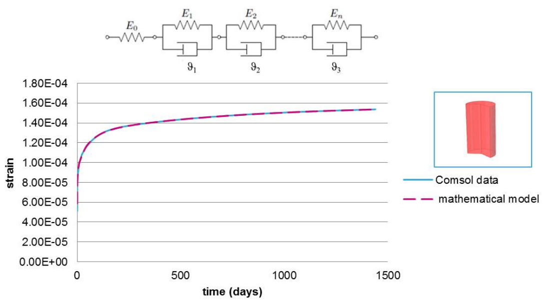

Figure 1: Comparison between COMSOL simulations of a creep experiment, based on a Kelvin-chain modeling of the material viscoelasticity, and the theoretical results calculated according to the ModelCode equations. In the simulations, a constant load of 1MPa is applied.

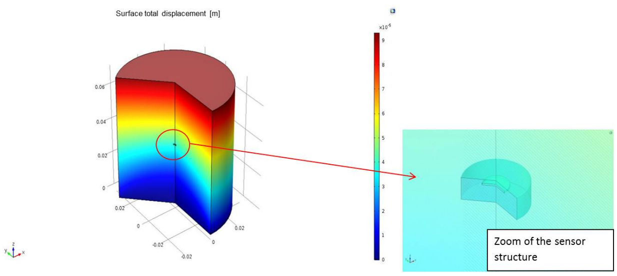

Figure 2: Geometry of the simulated system, representing a sensor structure embedded in a viscoelastic concrete cylinder.

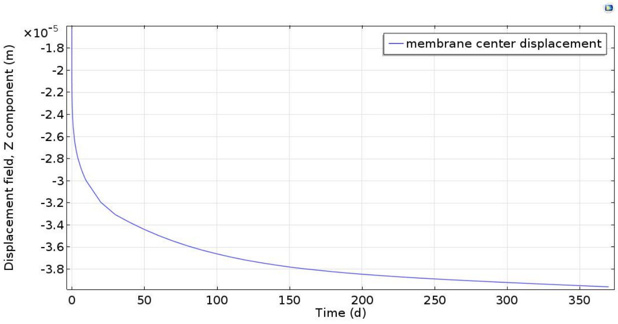

Figure 3: Vertical displacement of the membrane center for a constant load of 10MPa on top of the concrete cylinder. Deformation increase vs time is due to the viscoelastic creep.

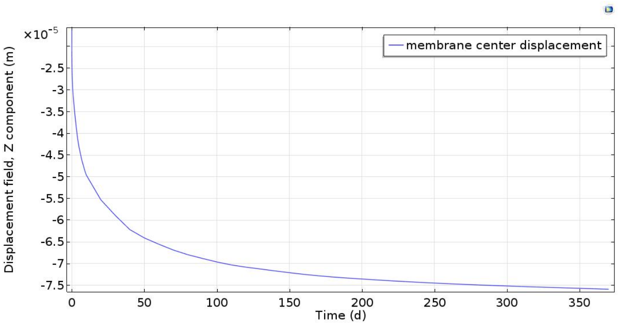

Figure 4: Vertical displacement of the membrane center for a constant load of 10MPa on top of the concrete cylinder, when considering the combined effect of viscoelastic creep and of concrete shrinkage strain.