Computational chemo-damage transport modeling of durability synergies in concrete

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October 2004

Abstract

The present work is but a small contribution to an emerging multidisciplinary area of research with considerable potential about durability problems in concrete. Deterioration of concrete infrastructures resulting from physical chemical attack by deleterious species accounts for a large proportion of durability problems. However, for sustainable development and associated social and economic concerns. It is necessary that the infrastructures retain their required durability and structural performance over the long term. The need for models that empower durability analysis and ordering of management systems such as schedule of repairs, service life design, service life prediction, as well as forensics that describe the deterioration mechanisms involved is imperative.

Most of these durability problems result from individual but often synergetic mechanisms of chemical attack following transport of deleterious species such as heat, moisture, chloride ions, carbondioxide, and sulfate ions into the concrete. For realistic conditions to which concrete structures are subjected in the field, the coupled impact of mechanically induced damage cannot also be ignored. Mitigation against such individual or coupled deterioration mechanisms can be made possible by scientifically studying the behavior of the various energy mass transfers, chemical reactions, and force mechanics that contribute to the degradation mechanism. Yet, most current migration methods for concrete degradation are empirical and depend on rule of thumb or curve fitting of extrapolations that are scientifically uncertain and therefore devoid of firm physical, chemical and mechanical foundations for prediction purposes.

In this study, analysis of durability and structural behavior of concrete under prescribed coupled chemo-mechanical conditions was proposed, formulated and implemented in a computational framework. The governing mathematical equations that idealize the tripartite physical-chemical-mechanical phenomena modeled into the framework are nonlinear and have to therefore be solved numerically. They were resolved in space using finite element method and in time using finite difference time-stepping scheme that are together capable of handling any geometry, prescribed initial and boundary conditions as well as material nonlinearities expected to occur during the service life of the concrete host structure.

Dubbed SConDur2D, which stands for 2-Dimensional Synergetic Concrete Durability, the computational framework developed is an amalgam of two other separate but operatinally interlaced computational systems called ConTra2D and LoiDam2D. ConTra2D, which stands for 2D CONcrete TRAnsport, models the most significant transport-reaction phenomena that contribute to the rate and amount of the concrete material deteriorating. It specifically models not only individual transport-reaction processes of various energies/species attributable to heat, moisture, chlorides, carbondioxide and/or sulfates, but also their synergetic influence on one another as experimentally observed in practice. LoiDam2D, which stands for 2D Load Indujced DAMage, uses continuum damage mechanics to quantify load-induced material defects or damage in concrete.

The centerpiece of the SConDur2D analysis framework developed in this study is the balance between the modular and coupled appeal of its operations. Despite the coupled appeal, the ConTra2D and LoiDam2D programs integrated within the framework underscores an equally modular appeal that makes it possible to simulate various dependent and independent durability-mechanics problems. In this study, sulfate attack simulations were conducted to demonstrate the predictive capability and adequate sensitivity of the SConDur2D analysis framework for parameters germane to the problem. In particular, the evaluation of strength reduction in concrete subjected to gypsum-based sulfate attack mechanisms were carried out. In this regard, a good agreement was reported when model results in this study were compared to experimental data in the literature.