In the light of recent tragic events, such as natural disasters, arson, and terrorism, studying the thermo-mechanical behavior of concrete at elevated temperatures has become of special concern. In addition, the fact that concrete has been widely used as a structural material in many critical applications, such as high rise buildings, pressure vessels, and nuclear plants, enhances the potential risk of exposing concrete to high temperatures. Accordingly, the potential damage to large-scale structures during the course of the fire, besides the possible loss of human life, emphasizes the necessity to better understand the thermo-mechanical behavior and failure mechanism of concrete exposed to elevated temperatures.

In this study, a one-dimensional model that describes coupled heat and mass transfer phenomena in heated concrete was developed. The mathematical model is based on the fully implicit finite difference scheme. The control volume approach was employed in the formulation of the finite difference equations.

The primary variables considered in the analysis are temperature, vapor density, and pore pressure of the gaseous mixture. Several phenomena have been taken into account, such as evaporation, condensation, and dehydration processes. Temperature, pressure, and moisture dependent properties of both gaseous and solid phases were also considered. Based on the results obtained from the numerical simulations, it can be seen the heat transfer processes in concrete at elevated temperatures are highly affected by mass transfer phenomena and associated phase change processes.

The proposed model is capable of predicting pore pressure values with a sufficient accuracy, which are important for the prediction of spalling and fire resistance of concrete.

The coupled heat and mass transfer problem was then studied by extending the proposed one-dimensional model so that it can be applicable in solving two-dimensional problems. Output from the numerical model showed that the maximum values of temperature, pressure, and moisture content occur in the corner zone of the concrete cross section, in which the pore pressure builds up right next to the moisture pocket towards the center. In addition, the model demonstrates the capability to solve the coupled problem in situations involving non-symmetric boundary conditions, in which conducting a one-dimensional analysis is of no use.

Simulation results clearly indicate the capability of the proposed model to capture the complex behavior of the concrete exposed to elevated temperatures in two-dimensional systems and to adequately predict the coupled heat and mass transfer phenomena of the heated concrete over the entire flow domain.

To predict the structural behavior of reinforced concrete members exposed to elevated temperatures, a three-dimensional fiber-discretized sectional beam model was developed to compute the mechanical responses of reinforced concrete structures at elevated temperatures. The temperature distributions obtained from the 2D coupled heat and mass transfer analysis were used as an input to the strength analysis. The model also accounts for the various strain components that occur in concrete and steel due to the effect of high temperatures. The constitutive models that describe the structural behavior of concrete and steel at elevated temperatures were also presented. To establish the validity of the proposed fiber model, a sequentially coupled thermo-mechanical analysis was implemented, in which the model predictions were compared against measured data from tests with good qualitative agreement. The developed model can be considered as an efficient and powerful tool to promptly assess the structural behavior and the integrity of the structure during emergency situations, such as fire events.

Major: Civil Engineering
Educational Career:
Bachelor's of Civil Engineering, BS, 2002, University of Kufa
Master's of Civil Engineering, MS, 2005, University of Kufa
Master's of Civil Engineering, MS, 2015, University of Central Florida

Committee in Charge:
Kevin Mackie, Chair, Civil, Environmental, & Construction Engineering
Manoj Chopra, Civil, Environmental, and Construction Engineering
Nicos Makris, Civil, Environmental, & Construction Engineering
Aravinda Kar, Optics & Photonics

Approved for distribution by Kevin Mackie, Committee Chair, on October 18, 2016.

The public is welcome to attend.