ABSTRACT

PERFORMANCE CHARACTERIZATION OF HIGH PERFORMANCE CONCRETES UNDER FIRE CONDITIONS

By
Wasim Khaliq
(Advisor: Prof. Venkatesh Kodur)
Monday, April 30, 2012, 1:00 pm
CEE Conference Room (EB 3546D)

In recent years, high performance concretes (HPC) are finding increasing applications in buildings and infrastructure due to numerous advantages, such as higher strength and durability, these HPC offer over conventional concretes. The use of HPC is most effective in reinforced concrete (RC) columns since the high compressive strength can be better utilized. Structural members made of HPC when used in buildings; have to satisfy the fire resistance requirements specified in building codes and standards. Although conventional concrete members have good fire resistance, same may not be true for HPC members due to faster degradation of strength with temperature and occurrence of fire induced spalling, which is attributed to differences in high temperature thermal and mechanical properties of HPC. The spalling in HPC members can be overcome either through the addition of fibers in the mix or by provision of modified 135° bent ties in RC columns. For evaluating the fire resistance of HPC columns, as well as to account for beneficial effects of fibers and 135° tie configuration on spalling mitigation, high temperature material properties of HPC (plain and with different fiber combinations) and integration of effect of tie configuration is required. However, there is lack of data on high temperature properties specific to different HPC (plain and with fibers) as well as established mechanism with which fire resistance in RC columns is enhanced with provision of modified 135° tie configuration. To overcome these knowledge gaps, an experimental and numerical study is undertaken as part of this thesis.

In the study, performance of HPC at both material and structural level (specifically columns) was evaluated. As part of material characterization, thermal and mechanical property tests were carried out in 20-800°C temperature range on different HPC mixes (plain and with different combinations of fibers). Thermal properties included of thermal conductivity, specific heat, thermal expansion, and mass loss, whereas mechanical properties comprised of compressive
strength, splitting tensile strength, elastic modulus, and stress-strain curves. Data from measured property tests was utilized to develop the high temperature material property empirical relations. As part of structural characterization, fire resistance tests were carried out on two fly ash concrete (FAC) and two high strength concrete (HSC) columns with different fiber combinations. These columns were well instrumented and tested under non-standard fire exposure to collect extensive data which included axial and lateral deformations, cross-sectional temperatures and strain in steel rebars.

In the numerical part of study, a macroscopic finite element (MFE) model, originally developed to evaluate fire resistance of RC columns was extended to include the effect of tie configuration. The proposed tie sub-model is based on the approach used in seismic design and involves calculation of force acting on ties by evaluating stresses resulting from pore pressure, mechanical loading and thermal effects in RC columns under fire exposure. The force on ties is compared against temperature (time) dependent bond strength (tie-concrete interface) to evaluate the failure of ties. Data from the material property and fire resistance tests was utilized to validate the numerical model by comparing concrete and rebar temperatures, deformations and tie failure times in HPC columns. The validated model was then applied to carry out parametric studies to quantify the influence of HPC material properties and effect of tie configuration on fire performance of HPC columns.

Results from high temperature material property tests show that HPC exhibit thermal properties similar to that in conventional concrete. However, mechanical properties degradation is much more severe (faster rate) in HPC as compared to that in conventional concrete. The addition of fibers into HPC slows down the degradation of mechanical properties namely, tensile strength, elastic modulus and stress-strain response. Results from fire resistance tests show that plain HPC columns exhibit lower fire resistance due to occurrence of fire induced spalling and faster degradation of strength. However these HPC columns can endure fire exposure (burnout conditions) without failure with addition of different fiber combinations in concrete mix. Parametric studies show bond strength in ties decreases at a faster rate due to fire induced spalling and direct exposure to fire. Higher pore pressure due to low permeability in HPC and higher applied loads on HPC columns lead to increased force on ties resulting in opening up/yielding ties.