Abstract

Fire represents one of the extreme loads that a structure may experience during its design life. In reinforced concrete (RC) structures, the mechanical properties of both concrete and steel deteriorates with rise in temperature. In addition, concrete subjected to elevated temperature shows two kinds of spalling, namely, explosive spalling and thermal spalling. While the rise in net tensile stress due to combined pore pressure and thermo-mechanical loading beyond the tensile strength of concrete results in explosive spalling, thermal spalling is caused due to the stresses developed on account of material degradation. The interfacial bond between steel rebar and surrounding concrete degrades at high temperatures resulting in bond-slip. Sustained compressive stresses and high temperature causes time-dependent deformation like creep and transient strains. A combination of these effects may result in early failure of the RC structure. Evaluating this complex response of the widely used reinforced concrete structural systems subjected to thermo-mechanical loading becomes vital in incorporating appropriate fire resistant measures in their design.

In the present study, an existing three-dimensional (3D) finite element (FE) model is extended to include effects of bond-slip and transient thermal strain for accurate prediction of the behaviour of RC assemblages under combined mechanical and thermal loads. The model considers the degradation of material properties with increase in temperature. A hygrothermal analysis accounting for the mass and energy transport that occurs within concrete is included for the estimation of temperature and pore pressure variations. Calculation of transient thermal strains are included along with mechanical and thermal strains in the analysis. Specific attention is paid in explicitly modelling the interfacial bond-slip behaviour between steel reinforcement and the surrounding concrete that leads to more realistic predictions of stresses, strains and displacements. Further, the work evaluates the uncertainty associated with the material properties used in the model through a stochastic framework. The probabilistic study includes identification and modelling of variable parameters, a stochastic analysis of the hygro-thermo-mechanical response and estimation of uncertainty in the response of the RC members.

The strength of the model is evaluated through the simulation of five benchmark problems that includes axial members, flexural members and a RC frame assembly. The results of the FE model are validated against corresponding experimental test data. The model is found capable of accurately predicting the thermal and mechanical response in addition to the spalling for normal and high strength RC concrete members under different loading and boundary conditions. The variation of local bond-slips with time is obtained in all the examples. At high temperatures, the slip due to differential expansion of steel and concrete is found to be more pronounced than the slip due to mechanical loads. A comparison of the fire resistance values obtained from the model against those determined from the code-based approaches shows that the code values are unconservative in most cases, especially when it involves high strength concrete or very high/low load ratios. The probabilistic treatment of the hygro-thermo-mechanical problem considering the variability in the material parameters provides a possible range across which the fire resistance of the RC element/assemblage may fall. As a step towards performance based design, it provides the necessary data required to evaluate the risk associated with these problems.