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Experimental behaviour of composite slabs during the heating and cooling fire stages

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ABSTRACT

Most theoretical and experimental research investigating the effect of fire on structures has previously concentrated only on the structural behaviour during the heating stages of the fire, partly due to the fact that internationally accepted standard fire tests only consider this stage of the fire. Evidence from real fires in real buildings has highlighted that the cooling phase of a fire is equally important and it is possible for structures to fail during this stage of the fire even though they have survived the heating stage up to a maximum fire temperature. This paper provides an insight into the behaviour of composite slabs under different fire scenarios considering both the heating and cooling phase of the fire. Extensive test data is presented which shows the redistribution of moments and strains in the deck and steel mesh, together with displacements during the full duration of the fire. The results show that the behaviour of composite slabs is dependent on the heating rate, the maximum temperature reached and the cooling rate. In terms of overall performance, displacements and the temperature on the non-fire side of the slab are important. For the tests presented in this paper it was shown that one fire scenario resulted in the maximum displacement but another fire scenario resulted in the maximum temperature on the unexposed face. In addition the maximum temperature of the unexposed side of the slab and the mesh reinforcement within the slab occurring during the cooling stages of the fire. This highlights the fact that the performance of structures must be checked in design under a range of possible fire scenarios, which must include both the heating and cooling stages of a fire.

1. Introduction

Research into the fire behaviour of buildings has predominately focused on the performance during the heating stages of a fire. The standard fire tests [1], which underpin the prescriptive methods [2] of fire resistance, are small-scale structural member tests subjected to a standard time–temperature fire curve that continues to increase in temperature with time. Once the standard test reaches a target time (typically 30 min, 1 h, 2 h or 4 h) the furnace is switched off and the load is removed from the tested structure. Standard tests rarely continue into the cooling stages of the fire and there is sparse detailed data on how structures behave as they cool down, although some researchers are beginning to slowly address this issue [3].

Tests on large-scale structures [2], which utilise natural fires, highlight the behaviour of the structure during the full duration of the fire. The tests on the Cardington frame [4] showed that the behaviour of the structure during the cooling stage of the fire is extremely important. For example, it was shown that failure of connections typically occurred during the cooling stage of the fire as the structure cooled. This was due to the heated beams and supported composite slabs expanding and losing strength and stiffness as they were heated. Restraint to thermal expansion, from unheated areas, caused the heated structure to absorb the expansion through inelastic behaviour by local buckling, squashing, or large vertical displacements. When the structure began to cool it started to contract from its inelastic state which meant that the distance between its ends got smaller inducing high tensile forces on the connections. Under these high tensile forces the connections generally fractured.

Previous work on modelling structures during the cooling phase has been reported [5,6]. However, as explained, experimental data to support modelling research work is sparse particularly for composite slabs which are more difficult to model than steel members due to the complexity of modelling the behaviour of concrete [7,8]. It was therefore decided to conduct a number of fire tests on composite slab strips and monitor the behaviour during both the heating and cooling stages of a fire. Different fire scenarios were considered to highlight the effect on the structural response due to different heating and cooling rates, different maximum temperatures, and different heating durations. The experimental behaviour presented in this paper provides an indication of the different structural response under different fire scenarios and

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