FIRE RESISTANT DESIGN OF CONCRETE FILLED STEEL HOLLOW STRUCTURAL SECTIONS

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Concrete filled steel hollow structural (CFS) sections are an economically and environmentally efficient, as well as aesthetically pleasing, means to support large compressive loads in buildings. The concrete infill and steel tube work together and provide several key benefits both at ambient temperature and during a fire. These members are now widely specified by architects and engineers and are increasingly being applied in the design highly optimized structural frames in the construction of multi-storey and high rise buildings as members where structural fire resistance ratings of two hours or more may be required.

Whilst the response and design of these sections at ambient temperatures is reasonably well understood, their response in fire, and thus their fire resistance design, is less well established. Current North American [1] and European [2] structural fire design guidance is available but has been developed based on tests of predominantly short, concentrically-loaded, small-diameter columns in braced frames using normal strength concrete. The current design models available are therefore rather limited and this means that the design of these columns must often be based on a detailed performance based analysis and design, which can be costly, time-consuming, and expensive. The aim of this project is to understand the fundamental heat transfer response mechanics at play within these sections and provide guidance on how to improve and simplify the design of these sections to ensure structural fire safety.

A meta-analysis of available furnace tests data developed during the past 60 years has demonstrated that currently available fire resistance design code methods for predicting the response of CFS columns in fire fail to capture the relevant mechanics observed in tests, and thus their ability to predict fire resistance when compared against the results of fire tests conducted worldwide is highly variable and somewhat limited. It has also demonstrated that the predictive abilities of the available design standards vary with respect to numerous physical characteristics of the CFS sections, such as shape and size.

It is well known that as the materials used in structural assemblies heat up they experience changes in thermal properties and reductions in mechanical properties, and material property models are available in the literature to account for this. Less well known, and thus less widely reported, is precisely how the distribution of temperatures evolves within CFS sections during fire and the factors influencing this, with most literature reporting only the steel temperature at failure and not the temperatures observed within the concrete core. Furthermore, the thermal evolution within protected CFS sections is even less known due to the paucity of widely available fire test data for protected CFS columns during fire. Fourteen large scale unloaded unprotected standard fire tests were conducted to assess the current ability to predict the thermal profile within CFS columns and to assess the effects of different physical sectional parameters on the heat transfer response. The most statistically accurate thermal modelling approaches developed through the previously described meta-analysis failed to accurately predict the temperatures within either the steel or the concrete, so a new 'best-practice' thermal modelling approach was developed based on the observed temperatures over the cross-sections; this was then used in a repeat meta-analysis assessment of the European [2] design codes to evaluate the new approach's performance. It was found to that the new approach is more accurate and consistent when interrogated across different physical parameters, and therefore can be more confidently used in the analysis and design of unprotected CFS sections in fire.

In practice, CFS columns are often protected to reduce the rate at which the steel hollow section is heated during fire, and this protection can considerably extend the load bearing performance of the section during fire; however only limited test data are available. To better understand the thermal evolution within protected CFS sections, 20 specimens protected with reactive coatings of different specific types and thickness were heated for two or more hours in a standard fire testing furnace under self-weight only (i.e. unloaded). As expected, the temperature evolution within the protected sections was observed to have a much shallower thermal gradient than that observed in the unprotected tests; thus the structural response of the unprotected and protected sections during fire is very different for the same steel section temperature. These tests demonstrated that the current method of prescribing the coatings based on a limiting steel tube temperature is highly conservative, and a new method of determining the effective section factor for the columns is proposed.

Protected concrete filled SHS sections require further investigation for fire resistance, particularly with respect to predicting the thermal response of intumescent fire protection coatings, determining the thicknesses of protection required, and the temperature limit to which the coating must protect the section. Because the European [2] design code procedures clearly show that the critical steel failure temperature of an unprotected column in fire is significantly higher than that of an assumed infinitely protected section (i.e. uniform cross-sectional temperatures), it is proposed that the design of protected CFS columns be based on this conservative assumption of a uniform temperature distribution, with the limiting temperature determined using the European [2] guidance for structural capacity calculations at elevated temperature.

This project has improved the understanding of, and provided best-practice modelling guidance for, CFS sections in fire.

[1] V. K. R. Kodur, “Guidelines for Fire Resistant Design of Concrete-Filled Steel HSS Columns-State-of-the-Art and Research Needs,” *International Journal of Steel Structures*, vol. 7, no. 3, pp. 173–182, 2007.

[2] CEN, “BS EN 1994-1-2, Eurocode 4 — Design of composite steel and concrete structures — Part 1-2: Structural Fire Design,” Brussels, Belgium, 2005.