Modelling of Concrete-Filled Stainless Steel Columns in Fire

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Summary

This paper investigates the finite element (FE) modelling of concrete-filled stainless steel tubular (CFSST) columns under ISO 834 standard fire, where heat properties, nonlinear material behaviour at elevated temperatures, enhanced strength corner properties of steel, and initial geometric imperfections were all included. Using the FE method, the behaviour of concrete-filled stainless steel tubular columns at elevated temperatures is compared with that of carbon steel composite columns.

Keywords: concrete-filled stainless steel tubes; finite element (FE) analysis; standard fire; fire performance.

1. Introduction

In recent years, there is an accelerating interest in the use of stainless steel in construction throughout the world. This is attributed to the fact that stainless steel is extremely durable, corrosion resistant, fire resistant and easily maintainable. A promising method to better utilise and compensate for the high cost of adopting stainless steel is to use hollow sections filled with concrete. The innovative composite columns combine the advantages of both stainless steel and concrete, and have the potential to be used widely in civil engineering projects.

Previous investigations on concrete-filled steel tubular (CFST) columns fabricated from stainless steel material have mainly focused on the behaviour at ambient temperatures. It is clear that there is a strong need to conduct wider research work on the fire performance of the composite columns. The fire performance of concrete-filled stainless steel tubular (CFSST) columns subjected to axial or eccentric loads is numerically investigated in this paper. The behaviour of CFSST columns at elevated temperatures is compared with that of conventional carbon steel CFST columns. Only square sections are dealt with in this paper.

2. Finite element model

Heat transfer analysis followed by nonlinear thermal stress analysis was carried out to predict the thermal and structural behaviour of CFST columns subjected to standard fire. In the heat transfer analysis, the surrounding temperatures were assumed to follow the ISO 834 standard temperature versus time curve.

Under standard fire, the temperature development in a column is affected by combined convective and radiative heat transfer. This can be simulated by heat transfer analysis. Then the following thermal stress analysis can be conducted in two steps. In the first step, axial or eccentric load was applied incrementally until the target load was reached. In the second step, the applied load was kept constant, and the temperatures were increased until column failure occurred, where the temperature fields were inputted using the results of the heat transfer analysis in last step.

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To fulfil the heat transfer analysis, three-dimensional FE models were developed. The material thermal properties, including the thermal conductivity, specific heat, density and thermal expansion coefficient, were required to conduct the heat transfer analysis. Those values for the concrete and carbon steel materials reported by Lie [1] were used in this paper, whilst those for the stainless steel material were taken according to EC3 [2].

For the thermal stress analysis, the Chen and Young's model [3] combined with the reduction factors recommened in EC3 is adopted to model the stainless steel material. The stress-strain model for carbon steel at elevated temperatures given by Lie [1] was used. The stress versus strain relation presented by Wang [4] was adopted to simulate the thermal stress property of the concrete.

3. Model verification

The FE models for carbon steel CFST columns at elevated temperatures have been verified by numerous test results [4]. Since no test result for CFSST column at elevated temperatures is now available, six test results on the fire performance of stainless steel columns reported by Gardner and Baddoo [5] were used to verify the models. From the comparison, it seems that the FE modelling proposed in this paper can predict the fire performance of stainless steel columns with reasonable accuracy.

4. Discussions

Four pin-supported CFST columns, including two axially loaded and two eccentrically loaded, were analysed to demonstrate the behaviour differences between the stainless steel and carbon steel composite columns. The temperature increases for the carbon steel tubes are a little faster than those of the stainless steel tubes after exposure to the fire for 30 mins. For concrete, the temperature differences are only found near the concrete surfaces.

Compared with the carbon steel CFST columns, the fire resistance for the stainless steel composite columns under axial and eccentric loading conditions increase 18 mins and 6 mins, respectively. Obviously, the CFSST columns show better fire performance than the carbon steel counterparts.

5. Concluding remarks

FE modelling of concrete-filled stainless steel tubular columns under axial and eccentric compression was performed in this paper. It was found that, the CFSST columns show better fire performance than the carbon steel counterparts under both axial and eccentric compression.

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